

TRANSACTIONS

of the
American Society for Steel Treating

Vol. VI

October, 1924

No. 4

THE October issue of TRANSACTIONS goes to press on the eve of the Sixth Annual Convention and Exposition of the Society, held in Boston, September 22 to 26, 1924. In the November issue, therefore, will appear an account of activities at the largest



The Cleveland Public Auditorium where the Seventh Annual Convention and International Steel Exposition will be held September 14 to 18, 1925.

convention and exposition which has been held by the Society up to the present time.

And now for Cleveland, the fifth city, and the Public Auditorium, where the Seventh Annual Convention will be held.

THE NATURE OF THE FUNCTION OF CHROMIUM IN HIGH SPEED STEEL

BY E. C. BAIN AND M. A. GROSSMANN

Abstract

This paper presents the results of the measurement of the effect of heat treatment upon three significant properties—hardness, impact strength and volume change—in the case of four high-tungsten steels. As far as is practicable the composition of these four steels is that of standard high speed steel except that the chromium content ranges from almost nil up to the usual 4 per cent. These data, in some measure, reveal the function of chromium in high speed steel. Photomicrographs are included which show the principal structural changes responsible for the effect of heat treatment upon the properties.

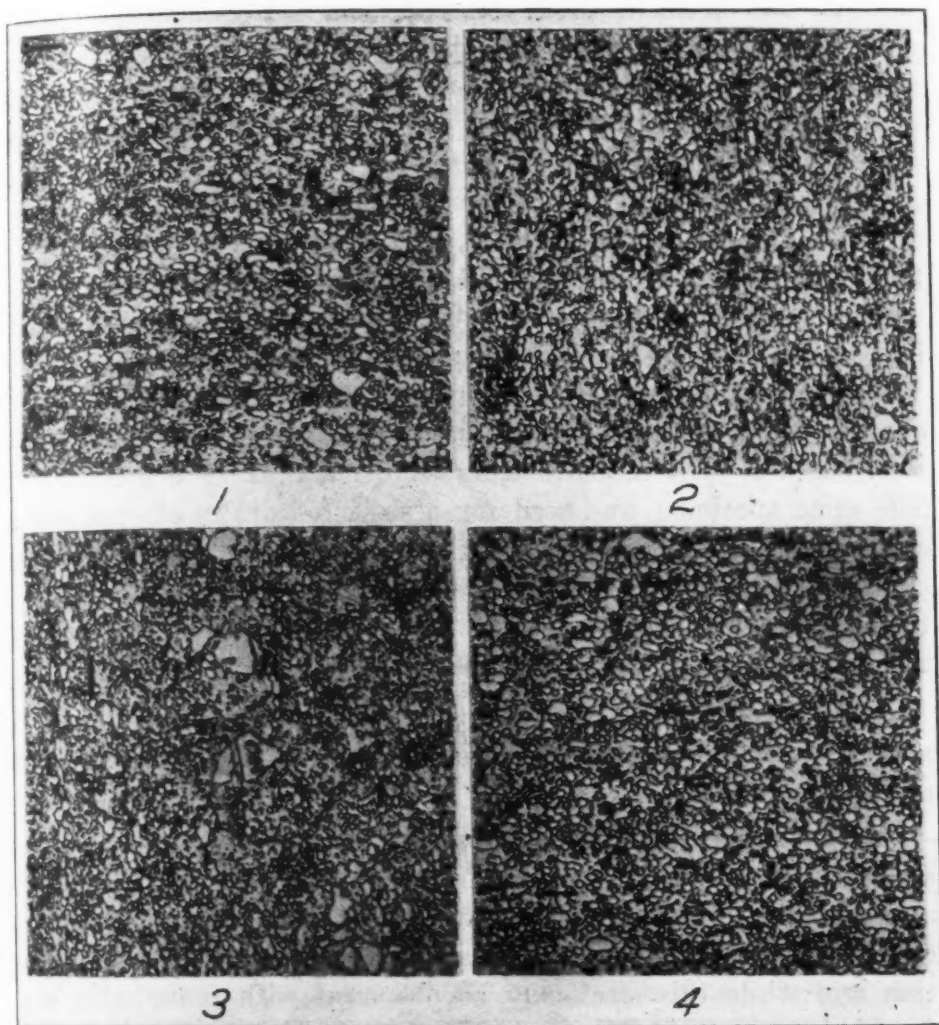
IT APPEARED to the authors that the obvious method of studying a steel from which chromium has been omitted in the crucible melt, as a means of discovering the chromium function, might be improved upon by a study of a series of chromium contents in high speed steel. It is to be regretted that in this series there were no specimens included with 8 or 10 per cent chromium as had been proposed, but there was too great a divergence in the proportion of carbon and tungsten in the steels available. The composition of the four steels studied is as follows:

	Steel No. 1	Steel No. 2	Steel No. 3	Steel No. 4
Carbon .....	.59	.55	.67	.60
Chromium .....	.25	.61	2.10	3.85
Tungsten	17.2	18.7	17.9	18.0

GENERAL METHODS OF EXPERIMENTATION

In order to make the tests entirely comparable, sound crucible ingots were cogged, ground, rolled and annealed in routine manner to produce good structure, in the accepted sense of mill practice. The annealed structure of the $\frac{3}{8}$ -inch square rods is shown in

A paper presented before the Sixth Annual Convention of the Society, held in Boston, September 22 to 26, 1924. The authors, Edgar C. Bain and Marcus A. Grossmann, Atlas Steel Corp., Dunkirk, N. Y. Written discussion is invited.



Figs. 1, 2, 3 and 4—Photomicrographs of the Four Steels Showing the Annealed Structure. Magnification 600x.

photomicrographs, Figs. 1, 2, 3, and 4, and is recognized as that of average good steel. The square bars from which all test specimens were made were satisfactorily free from decarburization. Specimens for hardness and impact tests were ground longitudinally after heat treatment. The heating for quenching into oil was done in a gas fired furnace well designed for uniform heating and equipped with a platinum thermocouple pyrometer. The specimens were drawn at low temperatures in oil and at high temperatures in a salt bath.

The specimens, $2\frac{1}{2}$ inches long, for the expansion and con-

traction measurements were also cut from the $\frac{3}{8}$ -inch square rods and were prepared with specially ground parallel ends. Test was previously made to determine the thickness of the thin skin of oxide formed on the parallel ground ends during the drawing period and even 1100 or 1200 degrees Fahr., in the process employed, produced only 2 or 3 ten thousandths of an inch thickness of scale. These specimens were, of course, ground parallel after the quenching, and the original length was taken as the length after a prolonged anneal at 1300 degrees Fahr., as experiment had shown this treatment to restore the steel essentially to the volume conditions after a thorough mill anneal. The length changes were followed by an Ames dial mounted above a plane steel surface. All measurements were made at 75 degrees Fahr. The same specimen was used for a series of draws after a single quench and it was unavoidable that the drawing effect should be cumulative. For this reason a slightly shorter time at drawing temperature was employed than is customary. The results here are obtained after $\frac{1}{2}$ hour at each temperature.

Before considering the results as presented in the curves it may be well to review very briefly the structural characteristics of high speed steel.

Perhaps the outstanding property of high speed steel is the sluggishness it shows toward diffusion. The tungsten atoms—and possibly to almost as great an extent, the chromium atoms—contribute this property. Diffusion is required for homogenization and while this steel may be prepared with remarkable uniform appearance at low magnification, it is actually, from the atomic standpoint, much less homogeneous than carbon steel. That is to say, properly annealed carbon tool steel is simply a matrix of pure ferrite in which spheroids of cementite occur. Annealed high speed steel has the particles of complex carbides (usually larger) in a matrix which is itself complex and which has constitution gradients and non-uniform composition.

The ingot of high speed steel, just frozen, consists of eutectic carbide and most severely cored dendrites of austenite. Subsequently, the eutectic carbide breaks up into small angular fragments as it is crumbled under the hammer or between the rolls. But the cored austenite matrix, as it cools, transforms to martensite, sorbite or ferrite plus carbide, depending upon the particular

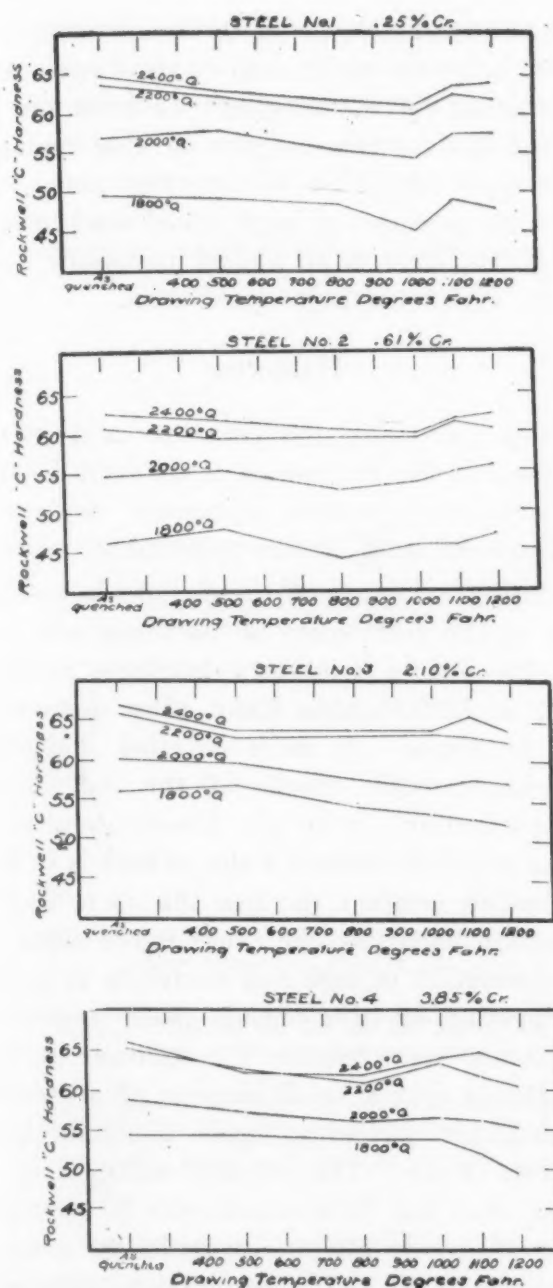


Fig. 5—Curves Showing the Effect of Quenching Temperature and Subsequent Draw upon the Hardness of the Four Steels. Each Point Plotted Represents the Average of three Rockwell Readings on Each of Five Similar Specimens.

concentration of alloying elements present at the point, and upon the rate of cooling. In the course of cogging and rolling with accompanying heatings, the diffusion is so limited that the non-

uniformity of the matrix is never quite overcome. However, the carbon probably migrates easily, and in those regions first solidified—although distorted by the forging—we have the reactions of a low-alloy steel, and near the complex carbide regions we find the reactions of a steel very rich in tungsten and chromium. The possibility of some portions of high speed steel reacting after the fashion of a carbon steel is an almost necessary consideration in interpreting the studies of high speed steel.

HARDNESS

The effect of quenching temperature and subsequent draw upon the hardness of the four steels is set forth in the four charts of Fig. 5. Each point plotted represents the average of three Rockwell readings on each of five presumably similar specimens.

The outstanding evidence of these plots is, perhaps, the general similarity of the four steels in hardness effects. Almost all of them show the strong secondary hardness resulting from reheating to 1100 or 1200 degrees Fahr. after quenching from 2200 degrees Fahr. or above. A more detailed inspection, however, reveals some characteristic trends of the individual steels. In several cases, particularly with the lower quenches, the preliminary hardening at a 500 degrees Fahr. reheat is in evidence. The higher the chromium content the less this is noticeable. In both points of secondary hardness, the cause is the same, for it results from the transformation of retained austenite to martensite. Due to the slow migration of tungsten, in many regions only carbon and some chromium are available for solution at low quenching temperature. Hence only a small amount of austenite is retained and this, just as in low chromium steels, is not mechanically stable above 500 degrees Fahr. The relative softness of the material shows, moreover, that but little martensite is present. When the quenching temperature is higher, austenite of great stability results from the solution of the tungsten-rich carbides. Indeed, it is likely that the tungsten-rich matrix in the vicinity of the large carbide particles remains ferrite even at 1800 degrees Fahr. Such a quenched material will show a marked secondary hardness at 1100 degrees Fahr., the temperature for the release of austenite, rich in tungsten.

Most important, then, we find that tungsten alone can pro-

duce marked secondary hardness at 1100 degrees Fahr. when quenched from a high temperature, and that *chromium increases the hardness throughout at all quenches and draws*. It seems likely that the presence of chromium may assist in the solution of tungsten in the austenite solid solution, as it is said to assist

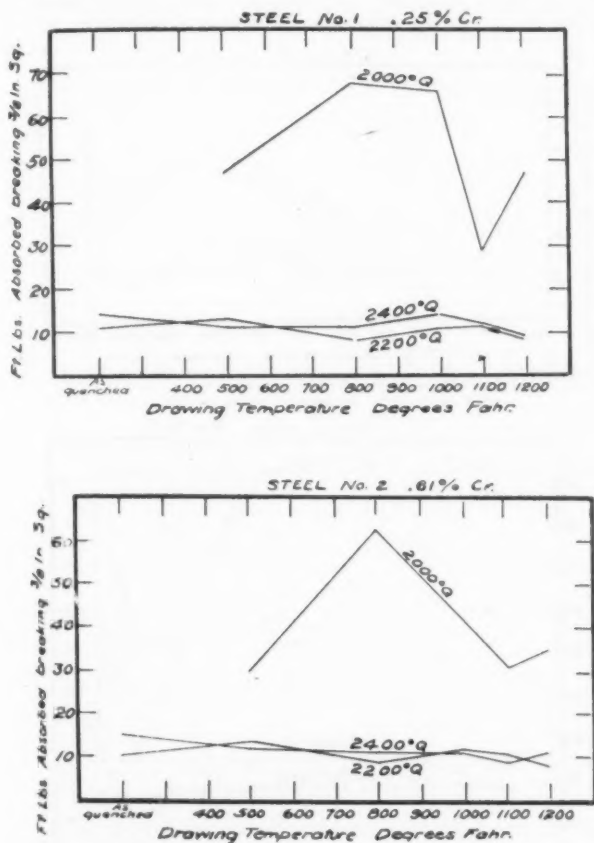


Fig. 6—Curves Showing the Values of the Impact Strength of Steels Nos. 1 and 2, as they were Affected by Heat Treatment. Each Point Plotted Represents the Average of Five Specimens Treated for the Same Quench and Draw.

in the melting of tungsten in the crucible. Chromium also tends to obscure the preliminary secondary hardness in the low-alloy carbon effect.

IMPACT STRENGTH OR TOUGHNESS

The four charts of Figs. 6 and 7 contain the values of the impact strength of the four steels as affected by the heat treat-

ment. The figures plotted are foot-pounds of energy absorbed in breaking un-notched $\frac{3}{8}$ -inch square bars, in a Charpy-type machine. Each point plotted represents the average of breaks on five specimens treated for the same quench and draw. We find here the sharp decrease in toughness at 1100 degrees Fahr. in the lower quenches, but in the higher quenches the toughness follows only

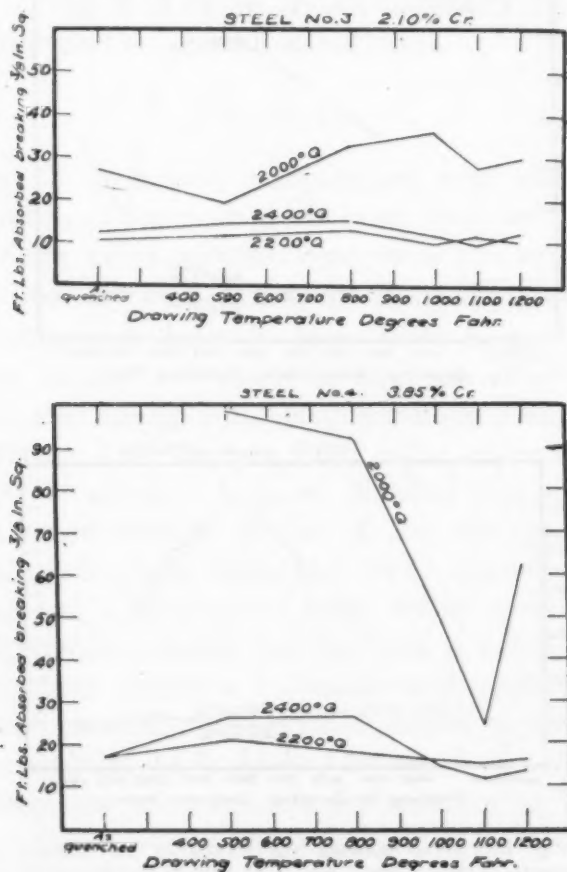


Fig. 7—Curves Showing the Values of the Impact Strength of Steels Nos. 3 and 4, as they were Affected by Heat Treatment. Each Point Plotted Represents the Average of Five Specimens Treated for the Same Quench and Draw.

roughly the hardness changes. However, in the 4 per cent chromium steel we discover the expected relation of brittleness accompanying hardness.

The great value of chromium is clearly seen here in that the steels become progressively tougher with increase in chromium content, and this fact is the more important when we recall that the previous charts of hardness developed the trend toward greater

hardness with increased chromium. To obtain greater hardness and toughness simultaneously is a most desirable circumstance.

The rather surprising toughness in standard high speed steel resulting from the 2400 degrees Fahr. quench and a draw at 850 to 900 degrees Fahr. is utilized in the industry for certain work where the tools are subjected to great shock. Structurally, such

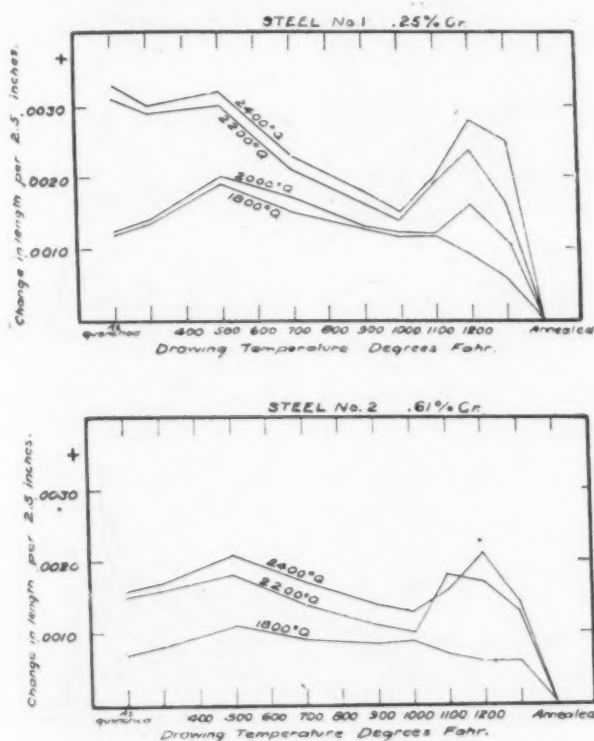


Fig. 8—Curves Showing the Length Changes in Steels Nos. 1 and 2, Resulting from Various Heat Treatments.

tools still contain much austenite, and the carbon in solution in the original martensite of the quench has formed a sorbitic structure which contributes no brittleness whatever to the tool, now essentially tough due to the austenite preserved.

EXPANSION AND SHRINKAGE MEASUREMENTS

The measurement of the dimensional changes accompanying heat treatment is, perhaps, our most delicate means of determining what transpires structurally as regards the modes of association of the components of the steels. With some experience, the entire structural history of a steel during heat treatment may

be closely deduced from such study. In the last analysis our knowledge of steels progresses chiefly as we learn what the atoms themselves are doing, and how they are associated in various constituents to produce desirable properties. The dimensional changes have been thoroughly correlated with the X-ray crystal analyses and with such close agreement that one can confidently interpret

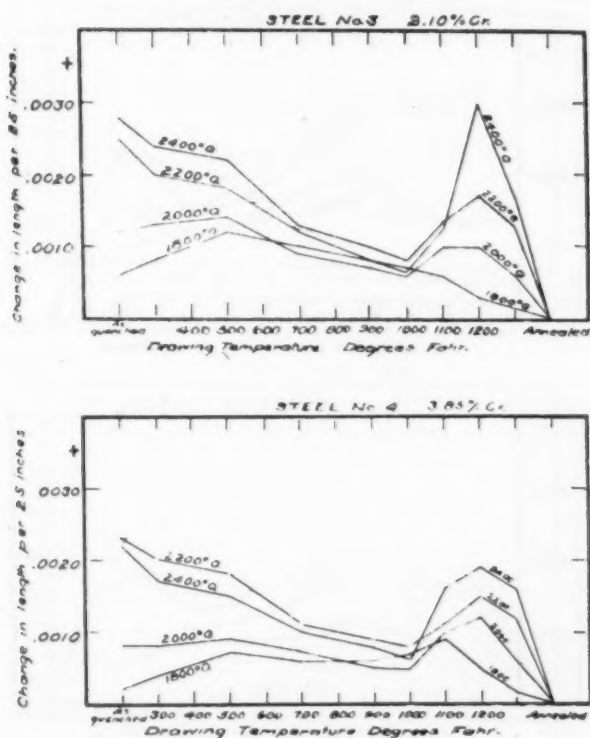
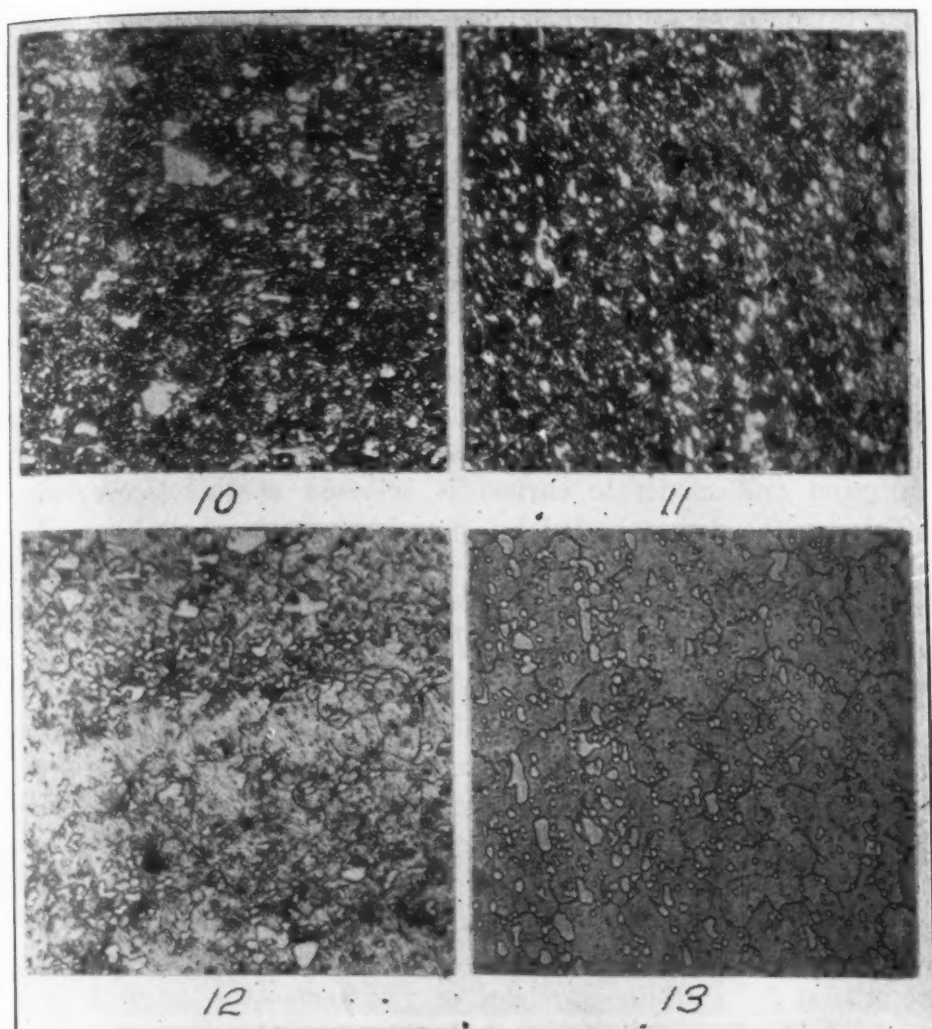


Fig. 9—Curves Showing the Length Changes in Steels Nos. 3 and 4, Resulting from Various Heat Treatments.

the change in volume of steels. Density (sp. gr.) measurements would be equally valuable if they could be made with equal accuracy, but experience shows that accurate density determinations are extremely difficult.

In brief, the carbide phase is most dense, austenite next, ferrite still less dense, and martensite (fine-grained ferrite containing carbon in solid solution) most voluminous. Hence, aging of martensite to produce tiny particles of carbide, plus ferrite, and the subsequent growth of the particles to sorbitic dimensions and to larger spheroids, all make for greater density. The change from austenite to martensite is accompanied by an increase in dimen-



Figs. 10, 11, 12 and 13—Photomicrographs Showing the Structures of Steels Nos. 1, 2, 3 and 4 respectively, Quenched from 2300 Degrees Fahr., No Draw. Magnification 600x.

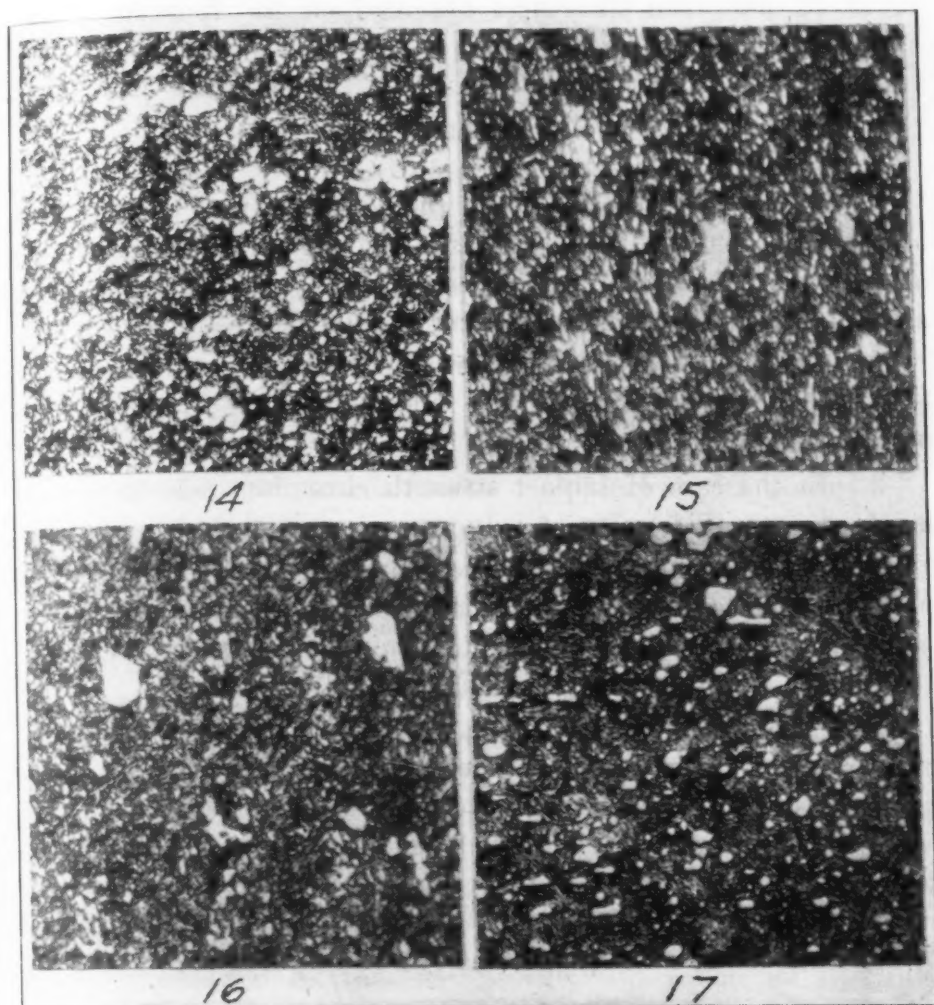
sions or a decrease in density. The evidence shows that although austenite lies intermediately between carbide and ferrite, nevertheless, high speed steel is, in the aggregate, most dense when thoroughly annealed. The drawing of high speed steels, after a high temperature quench, to 1200 or 1300 degrees Fahr., increases the density and is accompanied by shrinkage, but it may be seen that this effect is not at all smooth and continuous. In the four charts of Figs. 8 and 9 are shown the length changes in the four steels resulting from various heat treatments. Perhaps the most striking behavior to be observed is the close parallelism of these

curves to those of the hardness charts. The slight preliminary secondary hardness is accompanied by an initial expansion at 500 degrees Fahr. The strong secondary hardness at 1100 degrees Fahr. is paralleled by an enormous expansion at 1200 degrees Fahr. Reheating any of the steels beyond 1200 degrees Fahr. causes very rapid contraction and the concomitant softening.

The expansion, which reaches its maximum at 500 degrees Fahr., is most marked in the low quenches, and in the low chromium steels. However, it appears as a very distinct change in slope in the other cases. The only change in steel which could account for an expansion upon reheating is the austenite to martensite transformation. Austenite containing very little chromium and tungsten and moderate carbon is released at this temperature. (This can be demonstrated by quenching steels of such composition from high temperatures.) Hence there must be regions in high speed steel where tungsten and chromium are not available by diffusion for forming the rich austenite that can withstand higher reheating.

The shrinkage produced by drawing the quenched steel from 500 to 1000 degrees Fahr. is caused by the destruction of the voluminous martensite originally formed at the quench and at 500 degrees Fahr., and by the growth of submicroscopic carbide particles to the denser spheroids. At 950 degrees Fahr., high speed steel is essentially composed of, 1. Untransformed austenite formed at the quench; 2. Partially transformed martensite (troostite, etc.); and 3. Carbide particles of two sorts—the original fragmented eutectic and the reprecipitated spheroids.

These charts, even more clearly than the hardness charts, show the production of very stable austenite with tungsten alone, when quenched from high temperatures. The martensitization of such high-tungsten austenite occurs at a somewhat higher temperature than the same reaction for high-chromium steels. The secondary hardness contributed by tungsten is a much more distinct high-temperature hardness than that contributed by chromium. In regular high speed steel the secondary hardness reaction probably begins at about 1000 degrees Fahr. and is only just completed at 1200 degrees Fahr., although the grain growth has proceeded far enough at 1200 degrees Fahr. to cause the maximum to occur at 1100 degrees Fahr.



Figs. 14, 15, 16 and 17—Photomicrographs Showing the Structures of Steels Nos. 1, 2, 3 and 4 respectively, Quenched from 2300 Degrees Fahr., and drawn at 1100 Degrees Fahr. Magnification 600x.

The influence of chromium in obscuring the 500 degrees Fahr. effect is very clearly seen in steel No. 4. It appears that chromium assists not only in preserving more austenite for production of hard martensite at 1100 degrees Fahr., but also assists in diffusion in general, so that more austenite is produced at the quench. In fact there is a sufficient amount of austenite formed at a 2400 degrees Fahr. quench to make the steel softer than after a 2200 degrees Fahr. quench. However, the secondary hardness is greater the higher the quenching temperature. Photomicrographs in Figs.

10 to 17 show the structures obtained on the four steels after hardening at 2300 degrees Fahr.

CONCLUSIONS

1. Chromium increases both the hardness and the toughness of high speed steel. It increases the amount both of austenite and of martensite formed at lower temperatures, and particularly the amount of austenite retained after a 2400 degrees Fahr. quench.

2. Chromium serves to lessen the sharp concentration gradients throughout the steel. This follows from the levelling action on many of the curves.

3. In the case of impact strength chromium acts to produce much greater uniformity of values.

4. Tungsten alone in the steel quenched at very high temperatures causes a marked secondary hardness which, however, is accompanied by brittleness. Chromium appears to render the solution of tungsten into solid solution more rapid.

5. Chromium reduces the oxidation and scaling of the steel enormously during heat treatment. The specimens etched for photomicrography required very different lengths of time in the 5 per cent alcoholic nitric acid depending on the chromium content. The freshly quenched specimens of nearly chromium-free steel etched in about 15 seconds, while the normal high speed steel in the same condition required nearly two minutes.

NOTES ON THE HISTORY OF IRON AND STEEL

BY G. E. THACKRAY

Abstract

These notes have been selected from various records, writings, researches, investigations and explorations by archæologists, and others. They are, therefore, compilations of some of the salient points of history, the entire recording of which alone would require many volumes. One of the most complete and monumental works on this subject is that prepared by Dr. Ludwig Beck of Germany, comprising six large volumes of practically one thousand pages each, entitled "Geschichte des Eisens" (History of Iron).

FALLACIES REGARDING THE STONE AND BRONZE AGES

NUMBERLESS writings and traditions of history tell us that iron was produced by our very earliest ancestors, from its various ores with charcoal or similar fuel, operated with natural draft or with forced air blast in open fires, or small crude furnaces, and in this manner malleable or wrought iron was produced

There seems to be a somewhat popular belief, which has also been fostered by many public prints, that in more recent years there has been developed what is known as the "Iron Age," which has been followed by the "Steel Age," in which we now live, these being the alleged successors of the "Stone" and the "Bronze Ages."

With respect to the tonnage of iron and steel produced, and the more universal use of iron and steel, this is in a measure true, but it still remains that the knowledge of iron and steel has been brought down to us, step by step, with gradual improvements and increase in tonnages from the very earliest days. As far as we can go back into ancient history the use of iron was known by practically all peoples. Many of the earliest references to it are in the sacred writings of the Bible.

A paper presented before the Lehigh Valley chapter of the Society. The author, George E. Thackray, is special engineer, Bethlehem Steel Co., Bethlehem, Pa.

In Denmark there has been found near the shores of the Baltic Sea, many so-called household heaps, scattered in many places and of large dimensions. Upon exploration and excavation into these heaps, discoveries were made of knives, hatchets and other instruments of stone, as well as instruments of wood and bone mixed with charcoal and cinders, but there never has been found any instrument of bronze or steel.

The foundations of the stone and bronze ages were still further strengthened when none of the harder or metallic material implements were found. As the result of such excavations by archæologists, the announcement was made to the world of the famous stone, bronze and iron succession of ages, a dictum which has taken fast hold of men's minds.

It will be admitted, however, that the examination of geological deposits belonging to prehistoric periods does not reveal any iron or metal instruments, although it does reveal bone tools and implements. Investigations by archæologists in one part of the world may have revealed no metal objects, and other excavations made elsewhere may reveal only those of bone, and stone, while others again may reveal bronze and copper. Still other explorations and excavations elsewhere may disclose iron and steel implements, so that in each of these discoveries there may be a foundation for various beliefs. On account of the difficulty of determining exactly the chronological periods, differences of opinion have naturally arisen.

There is no doubt that man was acquainted with iron at a very early period, and this is logical for the reason that iron is readily reduced from its ores in a charcoal fire, thereby producing a mass of wrought iron or steel in a pasty condition. The ores of iron are distributed generally throughout the world.

On the other hand, the distribution of copper is more limited and occurs in forms more difficult to smelt or reduce from its ores. In order to produce bronze, other metals, such as tin, are required, the occurrence of which is not nearly so general as that of iron: the most notable deposits of tin being found in Cornwall, England and in the Straits Settlements; the Australian deposits not having been utilized until recent years.

As far as now known, copper could not be appreciably hardened by the ancients, although certain archæologists seem to think

that they could do so. Bronze, and copper, doubtless were somewhat hardened by arsenic or by the admixture of its oxides with itself, or by hammering. Such tools were used by the ancient Egyptians and others in stone dressing, but they used in connection with these, powdered emery or other hard granular substances, as abrasives, to assist them in their sculpturing.

Doctor Percy, the noted writer on metallurgical subjects, who has made careful studies in this respect, has become more confirmed in the opinion that archaeologists have generally been mistaken concerning the so-called "Iron Age." When we look to the ancient civilizations of Egypt, Proto-Chaldea, Assyria, on the one hand, or China on the other, the evidence of the earliest knowledge of iron is unmistakable.

METEORIC IRON

Doubtless, the ancients used some meteoric iron. Meteorites generally contain nickel and cobalt, and such material is difficult to cut from the mass. Also, only a few specimens are malleable, as most of them are admixed with stone or gangue of various kinds. Many masses of meteoric iron have fallen on this earth, numbers of such are now on exhibition in various museums. One of the largest was brought from the Arctic regions in 1894 by Commander Robert E. Peary, and weighs fifty tons, and is now on exhibition at the National Museum in Washington.

Certain of the people of the world might have used, at times, small amounts of meteoric iron, but the use of meteoric iron was not at all general and could not have been, for the reason that only about 240 meteorites have been found and recorded. The total weight of all known meteorites is said to be less than 200 tons.

These meteorites are widely scattered and could not form the basis of manufacture, as only a portion of these could be used in sporadic cases and to an inconsiderable extent.

BIBLICAL REFERENCES TO IRON AND STEEL

One of the earliest written histories relating to men and their activities is the Holy Bible, and in this there are more than fifty references to the use of iron and steel.

In the first book, Genesis, chapter 4, verse 22, it is stated that Tubal Cain was an instructor of every artificer in brass and iron. According to biblical history, Tubal Cain was of the seventh generation after Adam, and in accordance with some of the chronologists he lived at least 3700 years before Christ, or approximately 5600 years ago.

This reference from the Bible is in accordance with the prevailing present text, but some biblical students say that this should read, according to the Jewish text, that Tubal Cain was the forger or sharpener of every cutting instrument of brass and iron.

Again in Deuteronomy, chapter 3, verse 11, it is said that the giant Og, king of Bashan, had a bedstead of iron, and its length is stated as 9 cubits, which would be about 13.5 feet long. Again it is stated in the first book of Kings, chapter 8, verse 51, "for they are thy people, and thine inheritance which thou broughtest forth out of Egypt, from the midst of the furnace of iron." Many other references to the manufacture and use of iron occur in the various books of the Old Testament.

Again in the book of Daniel, chapter 2, verses 31 to 35, in the description of an interview between the king Belshazzar and the prophet Daniel, in which the prophet tells him of a great image which the king saw. He described the image as being made of fine gold, his breast and arms of silver, his belly and thighs of brass, his legs of iron and his feet part of iron and part of clay.

Iron is mentioned again in the book of Numbers, chapter 35, verse 16, which, in laying down the law given to Moses, states, "But if he smite him with an instrument of iron so that he die, he is a murderer," and in Deuteronomy, chapter 27, verse 5, in the instructions given to the Israelites, they are commanded to build an altar of stones and are enjoined, "Thou shalt not lift up any iron tool upon them"; and a similar statement is made in Joshua, chapter 8, verse 31.

In Judges, chapter 4, verse 3, it is stated that "the children of Israel cried unto the Lord," complaining that the captain of the hosts of the king of Canaan, into whose hands they were sold, oppressed them and that he "had nine hundred chariots of iron." In the first book of Samuel, chapter 17, in the description of the Philistine giant, Goliath, it is stated in verse 7, "and his spear-

head weighed 600 shekels of iron. In Second Samuel, chapter 12, verse 31, in the description of David and his army when they fought against Rabbah of the children of Ammon, it is stated, "And he brought forth the people that were therein, and put them under saws and under harrows of iron, and under axes of iron, and made them pass through the brickkiln."

In First Chronicles, chapter 22, verse 3, it is stated that before his death, "David prepared iron in abundance for the nails for the doors of the gates," and other materials, in order that he might build a house for the Lord; and a pointed reference to the manufacture of iron is to be found in Job, chapter 28, verse 2, which states, "Iron is taken out of the earth and copper is molten out of the stone."

These are only a few of the numerous references in sacred history to the use of iron, but are more than sufficient to indicate that iron has been known since the earliest days of history.

EGYPT

Following these biblical references, it is of further interest to note that the pyramids of Egypt, which were constructed, according to some authorities, 7000 years ago, and to others only 5000 years ago, doubtless required the use of iron tools for the cutting of the granite outer stones and the nummulitic limestone linings; but as the result of archaeological explorations, only a few iron instruments have been found buried under the pyramids.

Owing to the moist climate of Egypt and the consequent possibility that any iron or steel instruments would rust to earth again in the thousands of years, very few iron instruments have been found in Egypt. It is believed by some, that the Egyptians were not acquainted with the art of iron making, but that they imported their iron and steel from India, which latter country is believed to be the one, if not the earliest known seat of the iron and steel industry, conducted by our own Aryan progenitors.

Analysis of the tools of iron found under the pyramids show that they contain a very small proportion of nickel, but as they also contain carbon, they could not have been from a meteor, but must have been manufactured by the ancients from iron ores.

Herodotus, the Greek historian, who was born about 484 B. C., tells us of the great pyramids, stating about 100,000 men were

employed thereon for upwards of 20 years, and he expresses wonderment at the amounts that must have been spent for their board, their clothing and for the iron with which they worked. In further corroboration of this, an iron sickle has been found in recent years under the foot of one of the sphinxes at Karnak, Egypt, which is now in the British Museum, and indicates that this must have been made by a blacksmith at least 4000 years before Christ.

In 1837, J. A. Hill, an Englishman, found a piece of iron in the Pyramid of Cheops, when blasting the stones near the upper portion. This is a flat piece about $\frac{1}{8}$ inch thick, 9 inches long, and 3 inches wide, with irregular edges and covered with a blackish and brown, hard rust or oxide. It was found embedded between two layers of nummulitic limestone near the top of the pyramid and in such a location that it could not have been introduced there later, and was evidently left there by the workmen during the building of the pyramid, variously estimated at from 3000 to 4700 years before Christ. This iron was analyzed. Judging from its composition it could not have been of meteoric origin, as it contained a small amount of carbon and no nickel. This relic is now in the British Museum.

In 1837, Mr. Hartland, another Englishman, describes his visit to the Palm Tree Groves of Wady-Gherundel and the defiles, leading to Mt. Sinai in what is now known as Arabia, east of the Red Sea, and southerly a few hundred miles from the eastern end of the Mediterranean Sea. There he found the remains of many large charcoal iron works at a place called Surabit-el-Khadur. The remains of the furnaces indicated that they were constructed similarly to what we now know as the Catalan forge type, for making wrought iron directly from its ores. These works were operated during the rule of the earliest kings of Memphis, or during the reign of the Pharaohs, more than 4000 years ago.

Later, Gardner Wilkinson discovered pictures of Egyptian forges and bellows emblazoned on the walls of the tomb of Thotmes III—about 1500 B. C. These illustrations show a pair of bellows made of skins of animals, provided with openings and valves, operated by the feet of the attendants who held in each hand a cord attached to the valve, which was pulled for the purpose of inflating the bellows. The bellows were depressed by transferring the weight

from each foot alternately from one bellows to the other. Between these attendants was a charcoal heap and ore, with flames issuing therefrom. Above this was a picture of a crucible.

Metal sickles are also illustrated in the stone engravings of the Egyptian pyramids, together with pictures showing the farmers or husbandmen reaping the grain with such sickles.

King Menes of Egypt, who ruled about 4000 years B. C., built and had constructed all kinds of massive public buildings, dams, waterworks, etc., and it is believed that in order to enable him to do this, the workmen had iron and steel tools.

A large number of iron, steel and steel-like tools belonging to the time of the Assyrian invasion of Egypt, about 666 B. C., were found at Thebes and are now on exhibition in the Manchester Museum in England.

Previously Professor Petrie, F. R. S., says that iron was known in Egypt as long ago as 6000 to 7000 years B. C. and thereafter, this being well authenticated in the subsequent ages of the fourth and following dynasties. It is also known that the Egyptians used for stone working, copper and bronze chisels. Some of the hard stones were finished by hammer-dressing with stone discus hammers. Many of these stone hammers have been found. For saw and tool drilling they used bronze saws with granular emery, and in some cases they had bronze saws set with jeweled teeth. They also drilled holes in the stones with tools of metal tubes set with diamonds or the equivalent, in substantially the same general manner in which diamond drills are now used. Such saw cuts have been found in their quarries some seven feet long.

It is believed by some that the inscriptions found on the stones of the pyramids had been carved with steel and iron instruments, but as indicated by the study of all such arts, the knowledge thereof comes and goes. It is interesting to note that a Frenchman, only a few years ago, who desired a duplicate of some Egyptian carvings of stone, hired an Egyptian sculptor to make them. This artisan had a group of 100 tools of various kinds, which he inserted in wooden handles and used with a wooden mallet, but these chisels were of iron and required the constant services of a smith helper to sharpen them, by forging and cold-hammering.

Sir Robert Hadfield and others seem to be of the opinion that

India was one of the earliest known seats for the manufacture of iron and steel, and that its Wootz steel was imported into Egypt and used for cutting the large stones of the pyramids about 4700 B. C., or later. Other testimony which has been mentioned seems to indicate that the large stones of the pyramids were cut with bronze saws set with jewels and the holes drilled in them with diamond-set tubes.

Belzoni, an Italian, found an iron sickle under the foot of one of the sphinxes at Karnak, indicating about 600 B. C., but the authenticity of this may be in doubt, as it might have been introduced into the position in which it was found, at a later date.

It is interesting to note that a very old Egyptian mummy was exhumed and on investigation and preparation for exhibition it was found that the sarcophagus contained a set of ancient Egyptian iron surgical instruments.

ETHIOPIA

The Ethiopians or Negroes who lived in the countries south of Egypt, but separated therefrom by the desert, made iron in the earliest days by the use of charcoal fires, in small furnaces similar to those mentioned in connection with Egyptian industry. Illustrations in their burial chambers show this manufacture to be conducted in practically the same manner as that which is in vogue in that African country up to very recent times, and in some cases up to the present time. It is believed by some that the Egyptians drew part of their iron supplies from these Ethiopians.

INDIA

One of the earliest, if not the earliest, of ancient histories relating to the making of iron and steel, indicates that the East Indians, our Aryan ancestors, made both iron and steel in the very earliest historic times. In order to make the iron, the ore was pounded and separated from its matrix and was smelted with charcoal in a species of forge fire worked by skin bellows, thus producing in due course a small lump of sponge wrought iron, which was hammered with mallets to expel the scoria.

Crucibles were made of clay, mixed with equal parts of charcoal made from paddy or rice husks; moistened with water; trodden by oxen; and dried. Each crucible was then charged with

a small piece of iron from the previous operation, these pieces weighing from ten to fourteen ounces, together with five pieces of Tangaree or Cassia wood. A number of these crucibles, about 20, were placed in the form of a pyramid, some on top of the others, in a furnace resembling a very small blast furnace. These furnaces were built of refractory stones lined with and laid in clay; the clay sometimes extending above the top of the stones, forming a single stone or brick. The crucibles were then covered with two bushels of charcoal, a third bushel finally being added as firing proceeds. These furnaces were pear-shaped, 4 to 5 feet in height, 2 feet wide at the bottom and 1 foot wide at the top, sometimes made of clay and sometimes of refractory stones and clay. Bellows were used with bamboo nozzles for producing blast, these being operated by the feet or hands of the workman.

After the charge was made, the furnace was blown for about 3 or 4 hours, the crucibles then taken out and broken; a button of steel obtained from each. In more recent years the blooms of wrought iron were forged, with their initial heat, into pieces 1.5 by 0.5 inches in section and 12 inches long. These were cut into small pieces, weighing 0.5 to 1 pound each, for charging into crucibles, for the production of steel.

Iron was known in India from the very earliest periods and was used for all kinds of instruments, such as arms, tools, spears, and coats-of-mail. In some cases iron resembling steel, apparently was case hardened.

According to the best authorities there never existed a bronze age in India, on account of the prevalence of iron in that district. The analysis of some samples of "wootz steel," found in graves 3500 years old, 1500 years B. C., is as follows:

	Per Cent	Per Cent	
Iron	98.00	98.09	
Carbon	1.13	1.33	
Silicon	0.50	0.04	
Copper	0.30	...	
Aluminum	0.05	...	
Sulphur	0.14	...	
Silver	trace	0.18	
Arsenic .....	...	0.04	Specific
Carbon, Graphitic .....	...	0.31	Gravity 7.727

Wootz steel has a natural "damascene" or pattern, due to different qualities of material adjacent to each other in the button.

In the manufacture of wootz steel, green leaves are sometimes added to each crucible, and after the blasting is completed the furnace is cooled and the crucible broken and the button of steel removed.

The iron ore from which the wootz steel is made is of varying qualities, some high in gangue or rock, the richest portions being removed by hand sorting. The manufacture of wootz steel has been carried on in India up to recent times, and has been recently manufactured at Salem, on the coast of Coramandel and at Mysore, Lahore, etc.

The more recent steel makers bought their raw material, consisting of wrought iron, from the iron forges, in the shape of billets 0.5 by 1.5 by 12 inches, and cut them up into pieces of about $\frac{1}{2}$ pound each. The furnaces are made in the form of a parallelogram of stones, each about 12 inches long and 2.5 inches high, making a wall plastered with clay inside and out. The clay is built up higher than the stones, and in the front wall a clay pipe is built to receive the blast nozzle from the bellows.

A notable example of early iron manufacture in India is the column of Delhi, which is a solid shaft of wrought iron about 16.5 inches in diameter at the base and 12.5 inches in diameter at the top, and about 22.5 feet high above the ground and extending several feet into the ground where it has a bulb or onion-shaped base, supported on an iron-bar and stone foundation. It weighs at least 8 tons.

The date of the manufacture of the column is variously estimated from 900 B. C. to 319 A. D. It is composed of a number of wrought iron blooms welded together. The metal has been sampled and analyzed and found to be of good quality wrought iron.

On this column are many inscriptions engraved in various styles of cuneiform writings, sanscrit, etc., but these are believed to be of later times, in some cases quite recent.

Certain Indian temples, such as that at Karnak, have roofs supported by wrought iron beams 21 or more feet long and 8 by 8 inches square. Other beams 8 by 12 inches in section and more than 21 feet long have been found. These, however, are believed to be of a later date, or about 1200 A. D., and are of rather poor quality wrought iron, containing holes and laminations.

Another Indian column, even larger than that at Delhi, is that at Dahar, but this is in such an inaccessible desert district that complete details are not so well known. It is believed, however, to be as old as, or older, than the Delhi column.

King Porus of India, 300 or more years B. C., presented to Alexander the Great, a wrought bar of Damascus steel. About this time it is believed that hollow cast iron vessels of extreme thinness were also made, the quality of which can hardly be produced today. Colonel Pearse found in excavating some tumuli, of about 1500 B. C., at Wurre Garu, near Kamptie, in India, a number of gouges, spatulas, ladles and a variety of other articles which, like the old saw or pick from Assyria, testify that in the matter of the form and material of tools, we have gained little, if anything, since these examples left the hands of their fabricators 3500 years ago.

CHINA

China's ancient history records the use of iron at least 3000 years B. C., and while there was in that country an age which might be called the bronze or copper age, iron was used as early as either of these, although at certain times and at certain places bronze might have preponderated. There is a certain Chinese secular literature which is asserted to be at least 500 years older than the earliest accounts of the Hebrew Scriptures, and 1500 years older than any of the oldest cuneiform inscriptions yet found. In these ancient Chinese writings, steel is mentioned and iron was known at least 3000 years before Christ. Lech Tze, of 400 B. C., describes the process by which iron was made, at and before his time.

The Chinese had both wrought and hard iron or steel, and both of these were made in Shansi and Chilili in the Ho District, where there are great deposits of iron ore and coal.

MESOPOTAMIA

CHALDEA

One of the very oldest civilizations is that of the Chaldeans and their predecessors, the Sumerians. The Chaldeans lived in the alluvial plain extending from the Persian Gulf between the Euphrates and the Tigris Rivers, the land which was believed to

be the first inhabited after the Deluge and which, according to biblical students, contained the Garden of Eden or Paradise.

Explorations there have revealed many rings and split rings of iron dating from 2000 to 1500 B. C. Recent explorations, reported by the University of Pennsylvania, in the ancient city of Ur, revealed wonderful buildings, including a staged-tower and burial place filled with almost numberless instruments and implements of flint, stone, pottery and copper, dating from 5000 years B. C. The explorers, however, have not yet discovered or disclosed any iron specimens.

BABYLONIA

Babylonia, which was the cradle of Semitic civilization, stands prominent as being highly civilized and densely populated when Egypt was still in its youthful prime. It is certain that many of their records extend 2400 years B. C., and some archaeologists consider that they extend more than 2000 years earlier than that and that these peoples had iron manufactures and used iron from their very beginning.

MESOPOTAMIA

ASSYRIA

At the city of Nineveh, which was in its prime from 1600 to 625 B. C., and which was the capital of ancient Assyria, situated on the tributaries of the Tigris River of Mesopotamia, about 400 miles east of the north-eastern end of the Mediterranean Sea, at the palace of Nimrod, Mr. Layard found large quantities of iron in various forms, including the scales of armor. Each scale was made of iron and was 2 to 3 inches long, rounded at one end and square at the other, with a raised line or boss in the center. He also found armor of iron inlaid with copper, including a complete helmet which, however, fell to pieces on exposure. The Assyrian sculptors depict these.

Mr. Layard also found a pick or mattock of iron of almost the same shape as those now used. He also found an iron or steel saw almost completely turned to oxide, one end being broken off, the remainder being about 3 feet 8 inches long and about 4.5 inches wide, with a tang on one end to receive a wooden handle and with teeth formed and set like the crosscut saws of today.

These instruments date from at least 880 B. C. This mattock and saw are now in one of the British museums.

The Assyrians used iron, and their tablets have an inscription dating about 1300 B. C., which says: "I used chariots of iron to go over the steep mountains." Their archers had leather suits covered with scales of iron.

Victor Place, who, under the rule of Napoleon III, was the French correspondent at Mosul, conducted the excavations of Khorsabad. Among the ruins of the palace he found a magazine, or store-room, filled with iron billets weighing altogether 352,000 pounds. These billets were irregular pieces of soft iron weighing from 9 to 44 pounds each and were the commercial raw iron of that time. Each of these billets is pierced with a round hole through which a leather thong is passed for the purpose of forming them in bundles.

CEYLON, SUMATRA AND BORNEO

The islands of Sumatra and Borneo, off the Chinese coast in the East Indian Archipelago, and the Island of Ceylon, in the Indian Ocean, immediately adjacent to the southern end of India, and so close that it may be connected therewith by a railway, were very early seats of the iron industry, in various forms.

In Sumatra and Borneo, iron was produced in the earliest days in furnaces each about 3 feet 2 inches high and about 9 feet outside diameter, with walls more than 2 feet thick, made of dried clay, held together with rings of bamboo and blown with a wooden blast cylinder made from a hollow tree. This cylinder was about 5.5 feet long and 1 foot in diameter, and the piston thereof was made tight with feathers. The stroke was about 4 feet and the piston was operated by hand and a spring pole. The fuel was charcoal, which was mixed with the ore. When lighted and blasted the furnace produced a large lump of iron; about 90 pounds in weight. In order to facilitate the operations, the slag was tapped off several times per hour. After the lump of wrought iron was formed, the front of the furnace was broken out and the lump removed and hammered with wooden mallets to expel the cinder. The mass was then cut into a dozen or more pieces, which were again heated and hammered into bars of steely iron.

CEYLON

Not many years ago, explorations in the Island of Ceylon revealed hundreds of specimens of different kinds of iron, from the various buried cities which date back at least 500 years B. C. Among these specimens were chisels, the cutting edges of which were apparently case hardened and contain by analysis, combined carbon from 0.2 to 0.9 per cent, although most of the specimens, such as knives, sickles, pins, links, arrow and spear heads, washers, etc., are quite pure iron of good quality. Complete details and discussion of these Singhalese specimens appears in the *Journal* of the Iron and Steel Institute of Great Britain in a paper by Sir Robert Hadfield.

ANCIENT TROY

Some of the most interesting evidence relating to antiquity was obtained by Dr. Schliemann in his excavations of the city of Troy, in what is now known as Asia Minor, and of which Priam was king, regarding which Homer, the Greek poet, sung of occurrences of iron, at least 1000 years B. C.

Dr. Schliemann's excavations indicate that 4 or 5 ancient cities were superimposed upon each other, but his study of the remains does not indicate increasing civilization as time proceeds, especially in material things. They rather indicate otherwise, as the construction of the overlying cities is progressively inferior until it terminates in the Greek Ilian colonists, who had ceased to cut and dress stone, and who built their houses of wood. Dr. Schliemann also says that the evidence of excavations does not support the theory of the stone, iron and bronze ages, as such objects are found at every period, although less iron is found, due to its corrosion and exposure.

GREECE

Turning now to the civilization of ancient Greece—which was one of the best developed of those days—it is interesting to note that in Homer's *Iliad*, Achilles offers an iron disk, as a prize to discus-throwers. This iron disk had a weight of 36 pounds, being heavier than the ordinary discus used for this sport.

Doctor Schliemann's excavations confirm Homer's description of the advanced state of the metal industry of Greece. Mr. Rhind, after exploring the tomb of Sebau, discovered on the doors of the

inner repositories, "hasps and nails, still as lustrous and as pliant as on the day when they left the forge," and contended that iron was extensively used in Greece between the epoch of the Homeric poems, namely, 1000 to 900 years B. C., and the full historic period of Greece, and that within the same interval, if not earlier, iron was displacing bronze in Egypt.

Aristotle, the Greek writer and philosopher about 300 years B. C., explains that the Greeks of his time made and used steel. The shield of Achilles is described by Homer, and Aristotle describes the ancient method of making steel about 400 years B. C., a translation of this being:

"Wrought iron itself may be cast so as to be made liquid and to harden again, and thus it is that they are wont to make steel, for the scoria of iron subsides and is purged off by the bottom and when it is often defecated and made clean, this is steel.

"But this they do not often because of the great waste, and because it loses much weight in refining; but iron is so much the more excellent the less recrement (meaning dross or scoria) it has."

It will thus be seen that "waste" in steel manufacture, with which we struggle today, was known to the ancients, as well. A characteristic of that one-sided consciousness of superiority which showed itself prominently through so many phases of the Greek mind, during the climax of their history, was that they termed others "barbarians" and at that time thought that they, the Greeks, had discovered and first made iron and steel—whereas such were known thousands of years earlier, by others.

Daimachus, a Greek writer in the reign of Alexander the Great, about 370 B. C., speaks of four different kinds of steel, saying, "Of steel there is—

"The Chalybdic, for carpenters' tools.

"The Synopic.

"The Lacedæmonian for files, drills, gravers and stone chisels.

"The Lydian also is suited for files, drills, rasps, razors and knives."

The Chalybdites were the forerunners of the present Armenians.

According to the descriptions of other writers, the Greeks made steel, in some cases by boiling iron tools in molten sow-iron or

highly carburized cast iron, for various periods of time, whereby some of the carbon is transmitted to the tool and turns it into steel.

ROME

Pliny the elder, who was a most eminent naturalist and philosopher, and who lived about the time of the Christian era, namely, 23-79 A. D., wrote about steel, stating:

"The finer any edge tools be, the manner is to quench them in oil for to harden the edge, for fear lest the water should harden them over much and make the edge more ready to break out into nicks, than to bend and turn again."

This is a very early reference to water and oil quenching.

The Colosseum built by Vespasian and Titus, had many of its stones held together by iron clamps, and the holes therefor are found in some of their other structures, such as the Arch of Titus, having been built about the time of the Christian era.

ROME, GAUL AND BRITAIN

The Romans found during their invasions of Gaul, (now France, etc.) that the Gauls possessed swords and instruments of war formed of steel, having qualities even better in some respects than those which they had. They availed themselves of these instruments through conquest, and by adopting the niceties of iron and steel manufacturing as practiced by the Gauls. Among these instruments were the famous "Toledo" blades, which were made in Toledo, Spain.

Similarly, the Romans during Caesar's conquest of Great Britain, there found iron manufacturies and various implements of iron and steel. In addition to these manufacturies they instituted great iron works in the Forest of Dean, the remains of which are found today in vast quantities.

GREECE AND ROME

Some of the early notes relating to iron ore are found in the poems of Homer, about 900 B. C., and the hardening of steel by quenching is referred to in Book IX of his *Odyssey*, in the description of the blinding of Polyphemus, thus:—

"And as when armourers temper in the ford
The keen-edged pole-axe, or the shining sword,

The red-hot metal hisses in the lake:
Thus in his eyeball hissed the plunging stake."

The ancient civilizations of Greece and Rome were enriched by many examples of architectural art and mechanics, a large portion of which were destroyed when the barbarian Huns drove across the Volga in their war of conquest in the year 374 A. D., when they destroyed the iron manufactures of that time.

GERMANY, AUSTRIA AND SWITZERLAND

In Switzerland, hundreds of prehistoric forges have been found with clay crucibles and buttons of iron, surrounded by piles of slag and scoria, all dating from the Roman period. History also tells us that during the Middle Ages in those countries, steel was made by heating and partially fusing wrought iron and cast iron together, and during this period the sword smiths and armorers were of greatest importance, and guarded their trade secrets with jealous care.

One of the first larger blast furnaces known in Central Europe was in the Rhine Valley before the year 1443, and was operated by water wheels, and as the blast was more powerful it made cast iron, which at first was thought useless, but soon developed and became the useful material which it now is.

The old Stück-Ofen of Germany formed the link in the transition from the old Catalan forge to the modern blast furnace. The Blau or Stück-Ofen was first used in Styria in the 8th century, some of these furnaces being about 14 feet high, 4 feet in diameter at the tuyeres, and 2 feet in diameter at the top. There was but one opening at the bottom about 4 feet wide and 2.5 feet high, in which the tuyere was inserted and the hole closed with fire brick and opened again for withdrawing the iron. Iron ore was charged with charcoal, the charge containing about 4555 pounds of iron ore, resulting in a yield of 1400 pounds of wrought iron and 600 to 700 pounds of pig iron. The time of operation was about 15 hours. The fuel required was about 36.5 cubic feet of charcoal per 100 pounds of iron. The wrought iron was made and afterwards cut into pieces and refined in an open charcoal fire.

FRANCE

About the year 1400 A. D. two small iron furnaces were built

in the town of Lille, formerly in Gaul, now France, which town has recently been destroyed and pillaged during the World war.

BELGIUM

An example of the early iron manufactures we must include the large wrought iron cannon "Margarethe" of Belgium, which was 16 feet 6 inches long, with a bore of $25\frac{3}{16}$ inches and was composed of 32 wrought iron staves and 41 rings, the gross weight being more than 36,000 pounds. This cannon fired a stone ball 750 pounds in weight, the chamber holding 837 pounds of powder.

The ancient inhabitants of Belgium made iron as early as the time of Julius Cæsar, and it was also made in ancient Gaul, and in other countries now composing parts of the German Empire, Spain and Sweden. This manufacturing continued with improvements and modifications, up to the present time.

Case Hardening

During the Middle Ages case hardening was continued, one of the older receipts being:

"Take pieces of sheet iron, scrapings of horses' hoofs, salt or wood ashes—put into layers in a crucible—make red hot for several hours when the iron turns to steel."

In the tenth century Albertus Magnus recommended the use of the juice of radishes and angle worms for surface hardening of wrought iron.

Agricola

One of the most famous characters of metallurgical history is Georgius Agricola who, in 1556, published his famous work in difficult Latin, entitled, "De Re Metallica." Agricola's real name was Georg Bauer, meaning a peasant, and, in fact, his Christian name also means a peasant, or husbandman, but he Latinized this name and called himself Georgius Agricola. He was born at Glauchau in Saxony on the 24th of March, 1494. His book was a large folio replete with illustrations, giving full explanations regarding geology, ore deposits, and metallurgy of all metals as he knew it in that day, based upon his original study of the operations of his country. In his book, chapter 9, he states:

"Very good iron is smelted in a furnace almost like the cupel-

lation furnace. The hearth is 3.5 feet high, 5 feet long and wide, and in the center of it, is a crucible 1 foot deep by 1.5 feet wide, but it may be deeper or shallower.

"The iron master first throws charcoal into the crucible, then a shovelful of crushed iron ore mixed with slacked lime, and so continues. The fire is kindled and stimulated by the blast of a bellows, sometimes 8 and sometimes 12 hours. The mass of iron weighing 200 or 300 pounds is made, taken out and pounded with wooden mallets to condense and remove the slag, then hammered under an iron tilt hammer, then cut up into pieces and hammered into bars, etc.

"Iron thus made is placed again in the furnace with charcoal and heated and carburized into steel which is, when hot, plunged into water, broken and the fracture is examined to ascertain its quality."

STYRIA

As far as history tells us, the first cast-iron in larger quantities was made in a blast furnace in Styria, recently Austria, about the year 1350.

SPAIN

The manufacture in Spain of the ancient type of Damascus steel, dates back to very early times, and is believed by some that the manufacture of some blades in Damascus, goes back to the time of Abraham, or 1800 B. C.

It has been stated in more recent writings, about 1857, that the first process, as then conducted in Spain, was to mix oxides of iron and filings of iron in a crucible, which was placed in a reverberatory furnace. The crucible and contents was kept about 30 minutes in the fire so as to become a bright clear red heat. The fire was first lighted with charcoal and continued with coke. The crucible was then removed from the fire and exposed to the air to cool.

A second fusion was then made by taking 100 parts of the crystalline matter previously operated upon, and mixed with 100 parts of iron filings. After having been exposed to the fire for 1.5 hours a very pure metal was obtained for future operations.

It is stated by some that the so-called Damascus steel is sometimes made by placing three lines or strands of cast steel one

upon another, with or without, thin pieces or bands of iron between, and then welding together to form one plate, or bar. Tungsten (wolfram) has been used for this purpose in olden times, as one of the old formulas speaks of the use of six pounds of soft iron, 150 grains of wolfram, 144 grains of carbonate of manganese and pulverized nickel. The bars are freed from grease and immersed in a solution of distilled water and oxalic acid, which causes the various veins in the steel to appear. Damascus blades were sometimes made from steel so prepared. They were then buried in the ground for a long period of time, during which time the softer iron corroded, leaving the harder steel. From this, the blade was forged. Many stories have been told of the cutting qualities and resiliency of such blades, which in olden days were almost priceless.

SOUTH AND CENTRAL AMERICA AND MEXICO

In South and Central America and Mexico, to the early Incas, Aztec and similar nations which are believed to have originated in Asia, iron was known. Specimens were discovered by the Spaniards during their early visits to these countries.

POLYNESIA AND AUSTRALIA

As far as known, neither Polynesia nor Australia manufactured much iron in the early days.

Gunpowder

In the 13th century gunpowder was first used in firearms in Europe, although the Chinese or Arabs and others knew of it and made it long before the Christian era. This changed the armorers' art, and at the siege of Constantinople in 1452 a cannon was used of 34-inch diameter, throwing a stone of 850 pounds in weight, but this cannon burst at the first shot. Similar large cannons and bells were known in Russia hundreds of years ago.

Crucible Steel

The French physicist and chemist, Reaumur, who lived from 1683 to 1757, about 1710, made steel by the fusion of wrought and cast iron together in crucibles in a manner quite similar to that practiced today in the making of similar products. This process

somewhat resembles the pig and scrap process of the open hearth, except that at present the Siemen's regenerative furnace is used in order to obtain the high heat.

Reaumur also described in 1732, cementation furnaces for steels similar to those used in this country until a few years ago and which are still used in England.

MODERN BRITAIN

With respect to Britain of later date, it is interesting to note that Huntsman, a clockmaker of Sheffield, England, who is considered to be the first maker in England of crucible cast steel of the kind still made, and who was born in 1704, accomplished this manufacture and obtained a patent therefor in 1740. He produced this steel by first making cement or blister steel, which was afterwards broken into pieces and melted in crucibles to make it homogeneous. He also used for this purpose a secret flux, but from what we can learn, his process was little more than a mere carrying forward of the old East Indian process of making wootz steel.

Similarly in England, in comparatively recent years, Mushet has been given credit for the use of manganese for removing oxides from steel. He took out a patent therefor in 1856, whereas in 1839 Josiah Heath, also of England, had a patent for the use of the oxide of manganese for the same purpose. Huntsman also used black oxide of manganese for the purpose of purifying his steel at the date previously stated, about 1740.

Manganese was also used by other Englishmen for this purpose still earlier, as William Reynolds proposed this in 1799, John Wilkinson in 1808, John Thompson in 1819, Charles Schuthantl in 1835, by Heath in 1839, and Robert Mushet in 1856, and as applied to Bessemer steel in order to prevent its redshortness.

It is also interesting to note in this connection the contributions which various Englishmen have made to the manufacture of iron and steel. For example, Dud Dudley, in his book entitled, "*Metallum Martis*," published in 1665, therein recites his various difficulties in attempting to obtain and operate under his patent for producing pig iron from Pit Cole, Sea Cole, Peat or Turf, thereby conserving the timber, which even at that time was very scarce, and indicated that he made in this manner, gray iron,

motley iron, white iron and all kinds of castings. He obtained a patent for this from King James, but other Englishmen later also received other patents for the same process. Other Englishmen who were prominent contributors to the manufacture of iron and steel in the early days were Watt, with his blowing engine, about 1760; Henry Cort, who invented Puddling in 1784; the hot blast, first used by Neilson in 1828; Bessemer of England and Kelly of this country developed the Bessemer process in 1855, the details of which would be a story in itself; Gilchrist and Thomas introduced the basic process in 1879.

Siemens first designed his regenerative furnace about 1861, and the first furnace was built at the Montlucon works in France in 1863. Unfortunately the roof of this first furnace melted down. Later he built other furnaces at Birmingham, and still later in this country. About the same time Martin Brothers, of France, developed the use of the scrap and steel process in the Siemen's open hearth furnace.

One of the most successful methods in the art of turning cast iron into wrought iron was known as the puddling process, the credit for which is generally given to Henry Cort, of England, who developed this about 1784. Henry Cort was born in 1740, at Lancaster, England, and became a Navy broker, from which he gained about 20,000 pounds sterling, which he devoted to perfecting the manufacture of iron. He developed the puddling process of making wrought iron from pig iron, and also invented the grooved rolling mill, as prior to that, hammers had been used. He had patents granted him, but owing to the embezzlement of government funds and defalcation of his partners, who were officials of the British Navy, and regarding which he had no knowledge, he was unjustly sold out, his patents forfeited, and, instead of making the fortune to which he was entitled, he died a poor and disappointed man. His heirs also failed to obtain compensation, although after his death his guilty partners were absolved.

NORTH AMERICA AND UNITED STATES

Iron has been found in this country in early Indian graves; the Indians in some cases had wrought iron knives, chisels, etc. This is also equally true of Mexico and the South American coun-

tries. These discoveries, however, are quite recent as compared with those of Asia.

It might be interesting to note with respect to the manufacture of wrought iron, that more than 60 years ago Sir William Siemens worked for many years in attempting to develop a process for the manufacture of iron directly from the ore, but, unfortunately, without commercial success. Shortly thereafter Thomas S. Blair built a works at Glenwood, near Pittsburgh, and sunk his fortune and that of several friends in trying to make iron sponge directly from the ore and use it in steel making. The ore in that case was reduced by the gases from coal or coke, or aided in some cases by direct contact with the fuel.

In more recent years, in the early 90's, his son, Thomas S. Blair, Jr., together with a Mr. Adams, attempted to revive this manufacture, and although various experimental plants were constructed at different works, he also met with failure.

Many hundreds of inventions and attempts have been made in the last hundred years or so to revive, on a commercial scale, the ancient direct process of iron making; the Siemen's process, previously mentioned, having also been tried near Pittsburgh about 1880. We can only refer briefly by name to a few of the other processes that have been tried, such as the Jones' process; the Conley process; the DeLaval process; the DuPuy process, which was operated for a time with problematical success; the Laureau process; the Snelus process; the Turangin process; the Chenot process, which was used for a while in Europe; the Belford process; the Carbon Iron company's process; the Eames process, and others,—but practically the only one that was successful was a modification of the old Catalan forge or Bloomary process, as practiced in various parts of this country, and up to recent days, in the Lake Champlain district.

At the present time no direct method has been found which can commercially compete with the indirect method of making steel by first producing pig iron in large blast furnaces, yielding 500 to 600 tons per day, thereby readily and cheaply winning the iron from its ores. In a state of fusion the materials comprising the burden are easily separated, and by changing the mixtures, the burden, or the operation, the production of any desired quality of pig iron can be made; at the same time, the impurities are

fluxed away in a molten condition, thus yielding pig iron, which forms the basis for many subsequent processes of iron and steel making.

More than 75 years ago a certain type of steel was made in a puddling furnace by decarburizing cast iron and stopping the decarburization at the proper point, in some cases with the addition of hot pig iron from the bridge of the furnace, the whole thereupon being made into a ball and hammered into so-called puddled steel.

Another process for making steel, in use about 100 years ago, consisted of refining a cake or lump of wrought iron in a puddling furnace with inclined blast, covered with liquid cinder and made into raw steel and then further refined by being heated in contact with charcoal; the blast being carefully regulated.

UNITED STATES

One of the earliest references to the manufacture of iron in this country was made by Sir Walter Raleigh, who, in 1585, accompanied by Ralph Lane, made explorations up the Roanoke River in North Carolina. There they found a type of rock, which was found to be rich in iron.

Raleigh, however, was not particularly interested in iron, as he, like most of the early explorers and adventurers of that day, was looking for gold.

Ponce de Leon was here in the early days seeking the fountain of eternal youth, and, incidentally, gold. Cortez overran Mexico with the same idea, and Pizarro, with his followers, made his way to the west coast of South America in an endeavor to discover a room filled with almost solid gold, which was in the possession of the Incas of Peru.

As a result of this, this country was gradually developed, and farming, commerce, iron and other industries were founded by the early colonists, and it might be said, in passing, that the ruling incentive was to turn this iron into gold by commerce, inasmuch as the old alchemist's art of direct transmutation has never been perfected.

In about 1607 the first permanent English colony was founded near Jamestown, Virginia, by the Virginia company of London. In April, 1608, one of the first ships sailed from Jamestown,

loaded with iron ore and lumber, and this iron ore was smelted in England, and seventeen tons of iron were sold at 4 pounds sterling per ton to the East India company.

In 1619 the Virginia company sent a number of persons skilled in the manufacture of iron to Falling Creek, a tributary of the James River, about seven miles below Richmond. Unfortunately these works were delayed by the death of some of the workmen, the other men were slain and the works destroyed by the Indians in March, 1622.

As far as we can learn, the first real operating iron works in this country was established in Lynn, Massachusetts, or Saugus, in 1643 to 1645, and in 1648 Governor Winthrop, of Massachusetts Colony, wrote to his son, saying "that the iron runs eight tons per week and that their bar iron is as good as the Spanish."

Joseph Jenks built a forge at the Lynn Iron Works in 1647 and there manufactured scythes and other edged tools. Henry and James Leonard also constructed an iron works near Braintree, Massachusetts, in 1643, and another one was located in the town of Taunton, Massachusetts, about 1652. An early iron works was constructed in New Haven about 1663, and iron was made in Rhode Island by Joseph Jenks, Jr., a son of Joseph Jenks of Lynn, about 1675.

As the country developed and became more settled, other iron works were started and operated in New York State, Connecticut and New Jersey, there being 76 iron works in Massachusetts in 1774.

Notwithstanding the activity of the New England Colonists in the manufacture of iron for their needs; more lately they were discouraged in this procedure by the English government from time to time during the eighteenth century. About 1750 and thereafter, they were prohibited and hampered in the manufacture of iron, and it was required that they should import the same from the mother country. This was one of many causes leading to the Revolutionary war.

One of the first iron works in the State of New York was constructed about 1740 on Ancram Creek, in Columbia county, about 14 miles east of the Hudson River, by Philip Livingston, the father of the Philip, the signer of the Declaration of Independence. This was followed by the construction of iron works

throughout the eastern and northern portions of New York State; in Orange county at the Ramapo Iron Works, the large iron chain was made which blocked the Hudson River at West Point during the Revolutionary war; and particularly in 1800 in the Lake Champlain district, where large supplies of magnetite ores were found.

There was an early blast furnace plant in the heart of the Adirondack Mountains, between Lakes Henderson and Sanford, which was known as the Tahawas Iron Works and which attempted to smelt the titanic magnetite ore there found in large quantities along the East River. An ore dike formed a natural dam in the river, and extended thence into the hills. These iron works were abandoned about 1845.

The first mention of iron having been made in Pennsylvania was in 1692. However, the first really successful iron works were constructed by Thomas Rutter in 1716, north of Germantown. This was followed by the Manatawney forge in Berks county about three miles above Pottstown, and later the Pool forge was founded by James Lewis and others on the Manatawney Creek.

This was followed by others, notably the Coventry forge on French Creek in the northern part of Chester county in 1717, which continued its operations up to 1870. This was followed by the Colebrookdale furnace in 1720 on Ironstone Creek, Berks county, eight miles north of Pottstown, and this was followed by others scattered throughout the state.

Iron was also made in the early days in Maryland, Virginia, North Carolina, South Carolina, Georgia, Kentucky, Tennessee and Alabama. The early fuel of those days was charcoal, as timber was abundant and the iron manufacture naturally followed the location of the ores and the forests. There were in this neighborhood many small blast furnaces producing pig iron, one of which was the Hopewell Blast furnace built in 1759 in Berks county, which was the forerunner of the present E. and G. Brooks Iron Company's furnaces,—the Robeson furnace near Reading, the ore for which was taken from the Cornwall ore banks under a contract allowing the procuring of this ore for a nominal consideration as long as "water runs and grass grows," which contract is still in effect.

Later Iron Making

The puddling process developed by Henry Cort about 1784 was first performed on a sand bottom, in a reverberatory furnace. The furnace was built of fire brick with a large fire place at one end, a hearth intermediate forming a flat bottom, several feet in diameter and less than a foot in height, with a draft stack at the opposite end. The draft stack was generally provided with a damper for the purpose of properly controlling the flame. This furnace originally had a sand or coke bottom, but a later development provided it with what is known as a cinder bottom, formed by working a ball of iron scrap or cinder over the hearth while heating and fusing it gradually. The puddling furnace being operated at a high temperature, causes the pig iron therein to melt and become liquid, and this melted mass of iron is continually stirred or puddled by means of long bars called rabbles.

Flux, consisting of hammer slag, which is oxide of iron or sometimes ore, is supplied. The temperature is then increased, and the cast iron which originally contained a large percentage of carbon with some silicon and other metalloids, combined with the iron, boils and bubbles and blue flames of carbonic oxide gas issue therefrom. The iron soon assumes a bright appearance in spots, which is called "coming to nature," requiring constant attention on the part of the puddler and active work in stirring the same with his rabble before portions shall become set on account of the higher fusion point of wrought iron.

As the carbon and other materials disappear from the iron by oxidation from these processes, the temperature of fusion of the bath becomes higher and higher, but as the temperature attained by the puddling furnace is not sufficient to melt wrought iron, it then becomes a pasty and sticky mass, and by the skillful operation of the puddler it is agglomerated into several large, irregular, sponge-like masses, which are called balls. These are composed of more or less pure iron, in granules each of which is surrounded by a light covering of cinder, composed of the oxides of iron with some silica and other impurities.

These balls are withdrawn hastily from the furnaces by means of long tongs and are then transported on an overhead trolley to a hammer, or what is known as a rotary squeezer, where they are compacted roughly and form what is known as puddle blooms.

These blooms are then immediately rolled in the rolling mill, called a muck mill, by being passed backward and forward through the passes of the rolls and are thus drawn out into long bars, which are then known as muck bars and form the basis for future manufacture of iron bars. These muck bars are then cut into pieces of suitable length, piled together, placed in a heating furnace, heated to a welding temperature and then rolled backward and forward through rolls having suitable grooves, thus producing bars of various shapes.

In order to understand the manufacture of iron, it must be stated that cast iron made in blast furnaces is a comparatively brittle material, and this is due to the fact that it contains a large proportion of carbon absorbed from the fuel, namely: from about 3 to 5 per cent. Ordinarily the carbon is present in both the graphitic and free carbon condition. Cast iron also contains considerable quantities of silicon, which has been reduced from the silica of the charge, and this may vary from 0.5 to several per cent. It also contains considerable quantities of phosphorus, the lowest being about 0.02 per cent up to as high as 1 per cent. Some of these irons also contain varying proportions of manganese, while all of them contain some sulphur.

Passing now to the more modern practices of iron and steel making, it may be stated that the foundations of the business are iron ores, fuel and flux. The iron ores of the eastern portion of the United States, notably those of northern New York, are largely magnetite and in the early days these ores held the highest content of iron.

Magnetite ore, the formula of which is 3 parts iron and 4 parts oxygen, theoretically contains about 72 per cent of metallic iron; and in fact many of these ores were very pure and did contain 68 to 70 per cent iron. The purer portions of these deposits have been largely exhausted and the iron ores now available are somewhat leaner in their character and some of them in northern New York and elsewhere, are also alloyed with rather high percentages of titanium, which makes them difficult to smelt.

All of the early iron works of this country made wrought iron of various characters, directly from the ore, and it was not until later that pig iron and cast iron was produced. This wrought iron was made in what is known as forge or bloomary fires, the

larger and most important of which were known as Catalan forges or bloomaries. These furnaces had an open hearth, about 6 feet square, at the side of which was a fireplace from 2 to 2.5 feet square and from 15 to 20 inches or more in depth. The inside was generally lined with cast iron plates, the bottom plate being 2 or 3 inches thick. The back was formed of a stone wall, sometimes lined with fire brick and provided with a downwardly inclined tuyere or hot blast pipe entering therethrough directly down into the fire place. The blast was produced by wooden bellows, ordinarily formed of square wooden cylinders, driven by water wheels. The fuel was charcoal, obtained generally from the neighboring forests by carbonizing or charring the wood in heaps.

Various ore charges were used in these forges, from 300 up to 1000 pounds, but the more common charge was about 400 pounds. The hearth was filled with charcoal, the smaller pieces of ore piled against the charcoal opposite the tuyeres and then covered with the charcoal. The blast was then gently applied, gradually smelting and reducing the ore, and as the iron was melted or semi-fused, it dropped downwardly and formed a pasty mass in the bottom of the hearth. The fire was then urged more strongly, which caused the slag or scoria to melt and spread over and run from the iron. This was tapped from a convenient tap hole and allowed to run away, and after it was cooled it was thrown on the slag heap. The lump of pasty iron was then raised up and placed more directly in front of the blast in order to heat and agglomerate it, and then taken to the hammer or squeezer and shaped into a bloom, which was an approximately rectangular mass of crude wrought iron of various sizes, but ordinarily weighing about 100 pounds or more.

Following the manufacture of iron by the bloomary or forge fire, as in the earliest state of the iron making art, it was desired to make iron in larger quantities, and to this end larger blast furnaces were constructed, of which there were a number of examples of the early ones in this neighborhood.

These old blast furnaces used charcoal as fuel and were comparatively small in their dimensions. The stack was usually 30 to 35 feet high and carried a lining of common fire brick. The base of the furnace was about 24 feet square, and the top some-

what smaller, and these furnaces were generally located against a bluff or hill. Such a location was for the purpose of lowering the construction costs of the furnace and to enable easy transportation of the fuel, ore and flux to the top of the furnace, by means of tram roads or wagon roads on the adjacent hillsides. Generally only one or two tuyeres were used, and these were supplied with air by blowing engines of the crudest type, with very low pressures, and usually driven by water power.

These early blast furnaces were in most cases local institutions and used the native ores and charcoal fuels obtained from the neighboring forests. The ore was charged into the top of these furnaces by hand barrows. The charcoal was charged in a similar way and in addition to this, a varying quantity of limestone was used as a flux, depending upon the impurities in, or the self-fluxing character of the other constituents.

After the furnace was charged, the blast was turned on and the operation proceeded continuously. The furnaces were provided with an iron tap hole below, and a second tap hole above for the cinder. The product was known as pig iron, as it was cast in sand beds, the runner being the sow, and the pieces extending therefrom, the pigs. In those early times, a ton or a few tons a day was the ordinary output, but gradually step by step furnaces were increased in size and the capacity improved until they produced 10 to 15 tons per day.

Joseph G. Butler, Jr., of Youngstown, Ohio, in his recent address entitled, "Fifty Years of Iron and Steel Making," mentions a blast furnace at Youngstown, Ohio, in 1853, which made 6 or 7 tons of metal a day.

After the blast furnaces were started and some of the cast iron available for foundry use, castings, ordnance, etc., the next step in the art was to turn some of this cast iron into wrought iron.

Bessemer Steel

About the time of the Crimean war, Henry Bessemer invented a projectile to be fired from a smooth bore cannon, the form of this projectile being elongated and pointed, in place of the previously used spherical iron cannon ball. He demonstrated this at Vincennes, to Prince Napoleon, but discovered that this projectile required a stronger metal for the cannon than the cast iron or

bronze cannon of that date, and this led him to refine iron by the air blast, which he did in a stationary converter. He demonstrated and explained this to the British Association at their meeting in Cheltenham, England, in 1856, producing at that time samples of ingots and bars forged therefrom.

In the early 50's William Kelly, then of Kentucky, who had attempted to purify cast iron by the use of an air blast at Eddyville, Kentucky, went to Niles, Ohio, and tried to interest a Mr. Ward in this process in about 1854. He met with no success there and a few years afterward went to Johnstown, where he interested the officials of the Cambria Iron company sufficiently to try some experiments, whereupon he built a rectangular converter at their iron foundry, and attempted to purify cast iron or make wrought iron by blowing air through molten cast iron. As he did not understand the necessity for providing the necessary heat producing elements in the cast iron, this was more or less of a failure. He afterwards, however, developed this matter further and constructed and operated a rotary converter in 1861-1862, after Bessemer had operated a similar one in England. This converter is now in the Cambria Steel company's general office in Johnstown, as an interesting historical exhibit.

Before this time, Henry Bessemer had been working in the same direction in England, and filed an application for a patent in this country, and when William Kelly filed his claims for United States patent on a similar process, he found that Bessemer had filed his application here and had been granted a patent a few days previous. This led to what is known as an interference in the Patent office, and it began to look as if nothing could be done.

After this, however, Daniel J. Morrell, then president of the Cambria Iron company, representing his company with the Kelly and Mushet patents, had interviews with Messrs. Griswold and Winslow, of Troy, New York, with Alexander L. Holley, representing the Bessemer and Holley patents, and succeeded in composing the differences between the rivals, and formed a company in 1866 to develop and exploit the pneumatic process.

Following this, Bessemer steel works were constructed at Wyandotte, Michigan; Troy, New York; later at Harrisburg, Pennsylvania; Cleveland; Chicago; and in October, 1871, works were

completed and operations started in Johnstown. This was the beginning of the steel industry in that neighborhood.

Bessemer's United States patent No. 16,082, dated November 11, 1856, among other points, claims the following:

"The conversion of molten crude iron or of remelted pig or finery iron into steel or into malleable iron without the use of fuel for reheating or continuing to heat the crude molten metal, such conversion being effected by forcing into and among the particles of a mass of molten iron currents of air or gaseous matter containing or capable of evolving sufficient oxygen to keep up the combustion of the carbon contained in the iron till the conversion is accomplished."

William Kelly's patent No. 17,628, issued about seven months later, June 23, 1857, Reissued Nov. 3, 1857, Reissue No. 505, claimed as follows:

"Blowing blasts of air, either hot or cold, up and through a mass of liquid iron, (the oxygen causing a greatly increased heat and ebullition in the fluid mass) and decarburizing and refining said iron without the use of fuel."

Captain Robert W. Hunt, who was in Johnstown before and after the Civil war, and who was the first steel works chemist of this country, went to Wyandotte to learn the details of this manufacture; operated the plant there and then went to Johnstown again and remained for a number of years thereafter. Afterwards he went to Troy and became manager of the works of the Rensselaer Iron and Steel company at that place, and until his death last summer was in business as consulting engineer and steel inspector, with headquarters in Chicago, employing at one time thousands of men.

In this connection, we cannot but remember the work of the foremost engineer of that day, namely: Alexander Lyman Holley, who for some years was consulting engineer for the Bessemer steel makers of this country, and who made many trips to England and France to obtain information on these matters, and who put these into shape with his own improvements and embodied

them in the various steel works of this country. Mr. Holley was born in Lakeville, Connecticut, in 1832, and after following several different lines of endeavor, finally studied technics in the new course at Brown University, Providence, after which he was engaged in locomotive engineering, both on the road and in the shop and designing room. He also conducted various railroad and engineering papers with more or less success, but owing to the critical times preceding the Civil war, some of these resulted in financial failure. Mr. Holly was a most lovable man and at the same time a capable metallurgical engineer, and hundreds of engineers in the country united in testimonials to him on the occasion of his early demise, in 1882.

Generally speaking, the manufacture of steel by the Bessemer or pneumatic process consists in taking a quantity of molten cast iron, which in the early days amounted to only a few hundred pounds, and later 4 or 5 tons, but at the present day amounts to 12, 15 or 20 tons or more, pouring it into a large egg-shaped vessel provided with a refractory lining, the bottom being provided with a number of perforations, and then blowing blasts of cold air through the perforations and the bath of molten metal.

In the early days, the composition of metal required for the conduct of this process was not very well known and many failures resulted. As time went on, however, and practice was gained, it was understood that the silicon in the iron was the principal heat producing element. As the blowing continued this silicon was oxidized by the oxygen of the blast and burned, and by reason of the fact that the resulting product, silica, was solid, it remained with the bath or united with some of the iron, thus producing slag. This slag remained on, and added heat to the bath, so that at the end of the operation the metal was fluid and in a condition to pour.

For the ordinary acid Bessemer process, it was found that the best approximate composition of cast iron is as follows:

	Per Cent
Silicon	1.00 to 2.5 or more
Sulphur below	0.06
Phosphorus below	0.09
Manganese, variable but preferably ..	0.5
Carbon somewhat immaterial running	3.5 to 4.00 per cent
	part being combined and part graphitic

Iron containing more silicon, of course; contains more graphitic carbon and blows hotter and more fluid. During the early days of the Bessemer operation, the silicon content of the charge was comparatively high and frequently ran 2.5 to 3.5 per cent, but as the practice improved, the vessels were made larger, the operation more continuous, thus conserving the heat, and a very much less amount of silicon was required. Today good Bessemer steel can be made with about 1.25 to 2.00 per cent silicon or less.

As the process of blowing proceeds, the silicon and manganese are oxidized, followed by the carbon, which produces a very bright flame of incandescent gas which issues from the mouth of the converter. The blast is continued until the carbon flame practically disappears or "drops," whereupon the converter, which is mounted on trunnions, is turned to a more nearly horizontal position, so that the tuyere blast holes in the bottom are exposed and not likely to become filled with iron after the blast is turned off. The blast is then turned off and the addition of spiegel or ferro-manganese made in the vessel. This spiegel and ferro-manganese is an alloy of iron and manganese with considerable quantities of combined carbon. The name spiegel is derived from the German, meaning "looking glass," for the reason that the fracture of this material is very brilliant, due to the fact that its carbon is in a combined condition. Spiegel ordinarily contains 15 to 20 per cent of manganese, while ferro-manganese will contain about 80 per cent.

During the early days of the Bessemer process, Bessemer was unable to produce a steel which would roll properly, as it contained oxides and possibly sulphur. Robert Mushet, a Scotchman, came to the rescue and added spiegel or ferro-manganese, which on account of the facility with which manganese combines with oxides and sulphur, had the result of clarifying the bath and removing the oxides and some of the sulphur. The free oxides and other solid compounds generally pass into the slag or cinder, together with some of the sulphur, although possibly some of the manganese sulphide still remains in the steel, forming yellow or greenish occlusions. This was the solution to the Bessemer process and as time proceeded it became the popular method for the manufacture of steel, in immense quantities.

In the early days, the lining of the Bessemer vessels was

composed of silicious materials, or a compound of silica and alumina, silica being the largest constituent of the earth and in its pure state known as quartz, although ordinary sand and ganister rock are very nearly pure silica. Bottoms were generally constructed of burned fire bricks, which were made of a combination of silica and alumina and having bottom brick tuyeres, generally cylindrical and provided with small longitudinal openings, through which the air blast issues. Bottoms were also made of ganister mixed with clay and moistened with water and deposited in a pasty condition, and then dried in an oven.

One of the greatest troubles of the Bessemer process was due to the wearing out and fluxing of the bottom, owing to the violent action and extreme heat, whereupon Alexander L. Holley came to the rescue and provided a removable bottom, which, when it became worn, could be quickly replaced by a new one. As a result, American steel works immediately forged ahead and produced much larger quantities of steel from a given unit, than European works.

About 1878, Gilchrist and Thomas, two young English metallurgists and chemists, after numerous experiments and trials, suggested the use of a basic lining and bottom for the Bessemer converter. This lining is composed largely of burned dolomite, which is a natural stone containing both lime and magnesia. It is used for the purpose of eliminating the phosphorus from the Bessemer metal. In the acid Bessemer process, in which silicate of alumina, etc., are used for linings and bottoms, there is no elimination of the phosphorus and, consequently, iron ores or iron containing large quantities of this metalloid cannot be used to produce satisfactory steel.

This basic process was tried in England and after many failures it was found to be successful in eliminating phosphorus, whereupon it was introduced into Germany and elsewhere. In the basic Bessemer process the phosphorus is the principal heat producing element.

In the United States, however, we had large supplies of low phosphorus ores and there was little incentive to use the basic Bessemer process, although it was tried at Steelton, Pennsylvania, in 1884, and later at Pottstown, Pennsylvania, and at Troy, New York, for some years, but ultimately abandoned. In view of the

competition of the acid Bessemer works elsewhere in this country, these basic works could not continue to operate, as their costs were higher and their output less, so that at the present time there is not a basic Bessemer plant in the United States, although there are many of these in Europe.

Siemens Furnace

About 1862, Sir Charles William Siemens, who had been working on this subject since 1846, having been disappointed in his attempts to exploit his ideas regarding regenerative furnaces in Germany, where his patent claims were rejected by the technical office, on trifling and unreasonable grounds, went to England, and there began work in developing what are known as regenerative furnaces. This furnace utilizes a heat accumulator or regenerator, comprising a chamber generally located below the furnace, filled with fire bricks or other refractory materials in a loose manner, the bricks generally being piled in layers crosswise of each other in such a way as to provide a large number of flues or passages for the gas or air. As the waste gases issue from the furnace hearth, they are led downwardly through the regenerators and before passing through the stack to the outer air, they heat the brick-work in the regenerators, known as checkers.

After operating in this manner for a short time, say 15 or 20 minutes or a half hour, the current of gas and air is reversed so that the incoming gases and air are heated by the checkers before they unite at the entrance ports of the furnace, while the outgoing gases heat another set of checkers. This is a method for conserving the heat, so that the temperature of the furnace is accumulative, and in this way higher temperatures are obtained than in any previous manner, and with a saving of fuel. In order that this may be best accomplished, it is necessary that the fuel be gaseous, and in order to accomplish his purposes, Sir Charles William Siemens devised and constructed gas producers.

These are furnaces of various forms, provided with a fire brick lined chamber, either rectangular or cylindrical, having a grate or plate at the bottom and means for introducing air under natural draft or pressure from below. The air, together with some steam, which assists in cooling the bottom, breaks up the clinker and becomes dissociated, adding hydrogen to the gas.

As compared with an ordinary fire, however, these fires are much deeper, so that the coal on top is distilled gradually, the gases escaped from the upper portion, and are thence conducted in pipes to the furnaces. In other words, there is not sufficient air for combustion introduced into the producer chamber, so that the gas making is, in a measure, a distillation process.

Siemens first applied his furnaces to glass works production and the manufacture of crucible steels, but later on attempting to make open hearth steels, he met with many failures, owing to the fact that the people who built the furnaces condemned them too soon and were too impatient for results.

Therefore about 1868, he formed the Landore-Siemens Steel company and built a works in Landore, Wales. This proved to be very successful and in a measure was the beginning of the open hearth industry. Siemens used as his raw material, mostly pig iron, which he melted in the hearth of the furnace and removed the metalloids therefrom by adding ore.

About this time, Messrs. Emil and Pierre Martin, of Sireul, France, constructed some Siemens open hearth regenerative furnaces, but instead of using the pig and ore process, they used a mixture of pig and steel scrap, thereby reducing the time of making the charge and the quantity of ore used for deoxidation. This pig and scrap process is the one that is most largely used today. The open hearth process is generally known as the Siemens-Martin process.

The first open hearth steel furnace in the United States was built at Trenton, for the Cooper Hewitt company in 1868, but operated only a short time; while the first really successful open hearth furnace was built at the Bay State Iron Works in Boston, Massachusetts, about 1870, by Samuel T. Wellman, lately of the Wellman-Seaver Morgan Engineering company, of Cleveland. As in the Bessemer process, the open hearth process for many years was conducted on a hearth of acid character, formed of silica sand with slight amounts of impurities, such as iron oxide.

Iron Ores

The iron ores of the world are composed of various chemical and physical combinations, principally iron oxide combined and admixed with other materials, the most usual ones being mag-

netite, Fe_3O_4 , consisting of 3 parts iron and 4 parts oxygen, this, however, being a mixture of ferrous oxide FeO and the sesquioxide Fe_2O_3 . The next one, Fe_2O_3 , is composed of 2 parts iron and 3 parts oxygen, which is generally known as hematite. Another is limonite, which is composed of 2 parts of iron and 3 parts of oxygen, namely: Fe_2O_3 , together with 3 parts of combined water, more or less. Siderite or spathic ore is a carbonate of iron, containing one part iron and 3 parts carbonic anhydride, the formula being FeCO_3 . Another is Franklinite, which is a mixture of magnetite and zinc ores. Pyrite, which is a sulphur ore, is sometimes used for iron making after the sulphur is extracted.

Looking over the geological map of the United States, it may be seen that the deposits of iron ore follow the general trend of the Eastern and Appalachian mountain chains, beginning with small deposits in Maine and large deposits in northern New York, adjacent to Lake Champlain and in the Adirondack mountains. Extending downwardly along the Hudson river and west thereof it appears at intervals through Connecticut, into northern New Jersey, thence into eastern, central and western Pennsylvania, and down through Maryland. Considerable deposits are found on the eastern and western slopes of the Blue Ridge and Allegheny Mountains in the Virginias, and other small ones in the other mountains of West Virginia. It is found on both sides of the Cumberland and Great Smoky mountains through North Carolina and eastern Tennessee, with some scattered amounts in eastern Kentucky, thence into Alabama, where enormous deposits of comparatively high phosphorus iron ores have been worked for several years, but particularly in the last 30 years, where the output has been considerable.

There are, of course, many deposits of ore in other parts of the country, which were found later, particularly those in northeastern Texas; at Iron Mountain and Pilot Knob, in Missouri, which latter were once abandoned but now revived, and in the vicinity of Pueblo, Colorado, and elsewhere; at various places in Montana, with smaller quantities in California, Oregon and Washington.

In the early seventies large discoveries of iron ore were made in the Menominee district of the northern Peninsula of Michigan between Escanaba and Quinnesec. Prior to this in 1856 large

and pure deposits of specular iron ores and some magnetites were discovered and worked near Marquette, Michigan, and many famous mines were developed, notably the Champion and the Republic. The mines on the Menominee range were operated by the Menominee Mining company for a few years until those at Vulcan and Norway, Michigan, were purchased by the Cambria Iron company in 1882, and are now owned by Bethlehem Steel Company.

The late U. S. Senator Isaac Stephenson, of Marinette, Wisconsin, who formerly was a fisher boy on the St. Croix River, the eastern boundary of Maine, and who later was a lumberman in the Maine camps, moved to Wisconsin to develop lumber there and in the northern peninsula of Michigan. He was eminently successful and played considerable part in the development of the iron mines of that district.

Mr. Longyear, who went to Marquette, Michigan, in 1873, also played a large part in the development of the mines of the Menominee, Gogebic and other iron ranges of that neighborhood, and later was the first man to invest in mining lands in the Mesabi district of Minnesota.

The iron ores of northern Michigan are of a quality much superior to those found elsewhere in the country, by reason of their high iron content, their purity and the largeness of the deposits, enabling cheap operation. This was also helped in a large measure by the comparative ease and cheapness of transportation on the Great Lakes. The first cargoes were taken out in small vessels of a few hundred tons capacity each, but in 1873 a larger vessel, known as the Pelican, took a record cargo of 1250 tons; whereupon the calamity howlers of that day said that was too large and could not pay. As compared with this, it may be mentioned that lake steamers now carry 12,000 to 14,000 tons apiece, and are vessels of over 600 feet in length, 60 feet beam and other corresponding dimensions.

The lake ores are now taken from the mines and transported in dump cars to the docks on the lake front, there unloaded into ore pockets, which are immense ore containers, some of wood and steel, some of steel and others of concrete, constructed on the docks adapted to hold many cargoes.

A large lake vessel on arriving, locates itself at a dock, where-

upon its numerous hatches are opened, the ore chutes are lowered, the ore gates of the pockets are opened and ore pours simultaneously in 18 or 20 streams into the hold of the vessel, where it is trimmed and leveled by workmen, the whole operation of loading requiring ordinarily only about three hours, and at the most modern docks only about one hour, or a little more.

One of the vessels will make a round-trip between upper and lower lake ports, such as Cleveland, Buffalo, Erie, Conneaut, Ashtabula or Fairport in seven days or less; and when they arrive at the lower lake ports, they are unloaded mechanically by large grab buckets and the ore either piled on the dock or deposited directly into waiting trains, which transport them to their destination. Quite a large portion goes to the Youngstown, Ohio, district; other portions are delivered in the neighborhood of Cleveland, Lorain and Buffalo, western Pennsylvania and Ohio, while possibly the largest portion goes to Pittsburgh and vicinity.

There are certain railroads which haul mostly iron ore and coal, such as the Duluth, Mesabi and Northern; the Duluth and Iron Range; parts of the Duluth, South Shore and Atlantic; Chicago and North Western; and Chicago, Milwaukee and St. Paul, in the lake ore regions. In the lower lake district The Bessemer and Lake Erie operates from Lake Erie to Pittsburgh, while large tonnages of ore are transported on the Pennsylvania railroad; the Baltimore and Ohio and the Pittsburgh and Lake Erie railroads. It requires, however, three or four of the longest trains to transport the ore cargo of one large ore boat.

In 1885-6 some maps were made by United States geologists of the Mesabi iron district of Minnesota, which was north of the western end of Lake Superior, and in 1887, locations were made there by Mr. Longyear of 24,000 acres of land, based upon the information obtained from the geological surveyor. Unfortunately, the line which he obtained from this survey was somewhat inaccurate and only a small portion of his location was profitable; but within a week after his entry of 24,000 acres, at least 100,000 other acres of land had been purchased by others. This is the largest ore mining district of the world and contains the famous mines known as the Biwabik, Mahoning and others. The Mahoning mine is a large open cut, about a mile or more in diameter, and more than 200 feet deep, shaped like an amphitheater. Stand-

and railroad trains run into the cut on many miles of track laid on the benches or terraces of the pit, and are loaded directly from the deposits by immense steam shovels.

In the early days, the local ores in Pennsylvania were comparatively low in iron content, and high in phosphorus and sulphur and not adapted for steel making. This, together with their increased cost and the necessity for selection and roasting, caused them to be displaced by the better and cheaper ores of the lake districts.

For many years the iron content of the lake ores was at least 66 per cent iron, obtained by selection and working the best deposits, the phosphorus being about 0.04 per cent or less, and low sulphur, thus making these ores of Bessemer quality. Later as these deposits became more exhausted, the quality was necessarily lowered, and at present a blast furnace mixture contains ordinarily not more than 56 per cent of iron, and as the phosphorus is higher there is less and less each year of Bessemer quality, but this has been remedied by the use of the basic process, whereby the phosphorus is mostly eliminated.

At present hundreds of different kinds of ores are mined, tested and graded and each adopted for its best use. In the early days, only a small amount of earth covered the iron deposits, and the ore was easily obtained by stripping the overlying earth with steam shovels. Railroad tracks were laid in the excavations, thus making the work easier. The strippings now are heavier, but the mining continues in the same way.

Owing to the impetus given to business by the enormous mines of iron ore of excellent quality, lake shipping has developed by leaps and bounds, until now there are thousands of vessels of all kinds, from small to large boats, on the lakes. The tonnage of freight annually passing through the American and Canadian locks of the Sault Sainte Marie Canal and the St. Marys River, connecting Lake Superior with Lake Huron, is about 100,000,000 tons, all handled in about 6 months of navigation, this being a larger amount than that of any other port of the world! In 1916 lake vessels carried about 65,000,000 tons of iron ore, and in 1920 about 59,000,000 tons.

On the lakes, there are at least 820 vessels of about 3,000,000 total gross tonnage, with a carrying tonnage of about 4,500,000,

but during the last war about 500,000 tons were put into the ocean trade, some of which having now returned to the lakes.

In order to maintain the iron manufacture in the United States, and particularly for those plants which are located on or near the Atlantic coast, many foreign iron ore mines have been developed.

There is a group of iron mines in Cuba, on the south coast, of which the Juragua was first opened in 1884, and the Daiquiri in 1895. These ores are composed of a mixture of magnetite and hematite and are of Bessemer quality. They are obtained by surface mining and the ore bodies consist of irregular masses, overlaid with a comparatively small amount of earth or stripping. These ores, generally speaking, contain about 56 per cent iron, a trace of manganese, 0.04 per cent phosphorus, and 10 to 12 per cent silica.

Other mines on the north coast of Cuba produce Mayari ore which is of a peculiar quality. These mines were opened in 1905-1908, and consist of a mantle of low grade limonite resting on serpentine, resulting from the decomposition of this rock. These ores contain a considerable amount of nickel and chromium, and after the raw ore is nodulized, the product has about the following composition:

	Per Cent
Iron	55.00
Phosphorous .....	.018
Silica	5.00
Nickel	0.80
Chromium	2.00

The ore bodies are from 10 to 60 feet thick and lie just below the soil, with a very slight amount,—not more than two feet,—of stripping.

This Mayari ore in its raw state carries a large amount of moisture, both admixed and combined, and is clay-like in texture, containing only 35 to 40 per cent iron. The ore is treated in nodulizing furnaces and the product carries little or no moisture, but contains nickel and chromium, as previously stated. When mixed with other ores, it makes a wonderful iron, which is used for castings. Mayari iron may be mixed with other steel-making irons and scrap, producing a natural chrome nickel steel of most excellent qualities for many purposes, especially when heat treated.

Another mine is the Tofo, near Cruz Grande in Coquimbo Province, Chile, which consists of a large ore body of hematite and magnetite, forming the top of a hill about 2,000 feet above the sea, and 5 miles in a direct line from Cruz Grande. This is an ore which is high in iron, containing 65 per cent iron or more, and is almost entirely of Bessemer quality, some of it being quite low in phosphorus. These mines are entirely open pit. This hard ore, after crushing, is ready for immediate use in the blast furnace.

There are other mines in Mexico at Las Truchas in Michoacan, located south-west of Mexico City, and are about 6 miles from the Pacific Ocean. As yet these are in the development stage. These Mexican ores and their occurrences are in every way similar to those on the south coast of Cuba, and their tonnage in place is very considerable.

One of the oldest mines in the United States is that at Cornwall, Lebanon County, Pennsylvania, the ore from which has been used since 1741. This deposit is magnetite, which is a replacement of the limestone and is associated with, and results from, a trap dyke intrusion. The ore in its raw state is somewhat low in iron, containing about 42 per cent and generally carries some copper. It is granular and well suited to magnetic concentration.

The magnetic concentrates contain about 60 per cent iron, which is of Bessemer grade, and most of the copper may be removed on concentrating tables. This copper, when left in the ore, is useful in making copper-bearing steel, which from many trials and experiments, have shown such steels to be well suited to resist corrosion. More or less copper may be removed from the ore as desired, depending upon its use. These Cornwall mines are of the open pit type, but underground operations are now being developed and will be more important in the future.

These are the mines which were mentioned previously and in which the Robeson furnace has a small interest and the privilege of obtaining enough ore to supply one furnace "as long as water runs and grass grows." The product of the original furnace at Cornwall was used for casting cannon for the Revolutionary war, and although the furnace is no longer used, it still stands and is maintained in good condition as an object of historical interest.

BETHLEHEM AND VICINITY

It is only natural and proper while speaking here in the historic city of Bethlehem, which was founded in 1741, to remind you briefly of a few of the historic features and achievements of some of our predecessors and those of the company which forms the nucleus of this community.

This general neighborhood was one of the earliest seats of the iron industry of the United States, and more than 200 years ago, namely, about the year 1716, Thomas Rutter and his associates built the Bloomary forge on Manatawney Creek, about three miles above Pottstown, and a few years later, about 1720, they erected a blast furnace near there, calling it Colebrookdale.

The records also show that on account of the Colebrookdale furnace, a road was needed to connect it with the Manatawney forge, regarding which the late Samuel W. Pennypacker, Governor of Pennsylvania from 1903 to 1907, states that one of his ancestors, Henry Pennypacker, was foreman of the jury which reported on March 2, 1726, stating that "they have laid out a road from Colebrookdale furnace to Pool forge, and from thence to the great road leading to Philadelphia."

Many other forges and furnaces, in that and this neighborhood, were built soon thereafter, but the principal blast furnace in this immediate neighborhood was not started until a few years later, this being the old Durham furnace on Durham or Cook's Creek, about 1.5 miles from its entrance into the Delaware River, which was built in 1727 by a company of fourteen persons, and in November of 1728 James Logan shipped some of this pig iron to England. There were also a number of forges on this creek below the Durham furnace, and on both sides of the Delaware, which were supplied with pig iron from this furnace. Many other furnaces and forges were built in this neighborhood—in fact, too many to refer to categorically.

It was in this vicinity, also, that mineral fuel, namely, anthracite coal, was first used in this country, although the use of so-called stone coal goes back to a much earlier date in Europe and elsewhere. In the beginning, anthracite coal was used by mixing it with charcoal in the Harford furnace in Maryland in 1815, and between 1824 and 1828 Peter Ritner used anthracite coal mixed with charcoal in a charcoal furnace in Perry County of Pennsyl-

vania. It is also stated that in 1811 Francis McShane had a cut-nail factory at Wilkesbarre and used anthracite coal in smelting the iron.

In 1826 the Lehigh Coal and Navigation company erected at Mauch Chunk a small blast furnace and attempted to use anthracite coal, but this was not so successful.

In 1831 Dr. Geissenhainer filed a patent in Washington, which was granted in 1833, for the manufacture of iron and steel by the use of anthracite coal and hot blast, and later proceeded to build a furnace called the "Valley furnace" on Silver Creek in Schuylkill County, about ten miles north-east of Pottsville, and successfully made pig iron in it, using anthracite coal exclusively.

In 1837 Joseph Baughman and others, smelted iron ore, using about 80 per cent anthracite coal and 20 per cent charcoal, in the old furnace of the Lehigh Coal and Navigation company, at Mauch Chunk. In 1839, the agents in this country of George Crane of Yniscedwin, South Wales, who had bought Dr. Geissenhainer's United States Patent, advertised that they would grant licenses under it, to smelt iron ores with anthracite fuel and hot blast. Others followed this practice and at the Catasauqua furnace of the Lehigh Crane Iron company in this vicinity, David Thomas of Wales made pig iron, using anthracite coal, and this furnace made its first cast on the 4th of July, 1840.

The beginning of the Bethlehem Steel company was in 1857, when a company under the title of the Saucona Iron company was incorporated by a number of gentlemen of Northampton and Lehigh Counties, the name, however, being changed in 1859 to the Bethlehem Rolling Mills and Iron company, and again changed in 1861 to Bethlehem Iron company.

On July 16, 1860, operations were begun for the construction of the furnaces and mills, but this was delayed by the Civil war. However, the first blast furnace was started in January 4, 1863, the puddle furnaces were completed and began operations about three weeks later, and the first iron rails were rolled in September of that year.

This company at first had blast furnaces, puddling mills and rolling mills and proceeded regularly with its work, until in 1873 it completed a Bessemer steel plant, the first blow in which was

made on October 4, 1873, and the first Bessemer steel rails were rolled on October 18th of that year.

About 1885 the Bethlehem Iron company became interested on behalf of the United States Government, in a project to furnish it with guns and armor plate for the program of defense which was just then becoming prominent, and several company officials went to Europe to study and investigate this subject. This program of extension required more open hearth furnaces and other apparatus, and it was decided to construct the largest hammer in the world, namely, a 125-ton dead-weight hammer, which was used successfully for a number of years, in making armor and other large forgings.

Owing to the progress of events and improvements, this hammer was dismantled in 1902, having been some years previously replaced by hydraulic presses, according to the more modern system of producing large forgings. The original Bessemer plant was also dismantled at the same time.

The material for ordnance was made largely from fluid pressed steel, thereby providing material which was better and more solid than that otherwise produced at that time. The first contract for modern armor plate made in the United States was concluded by the Bethlehem Iron company in June, 1887, with the United States Navy department—including the armor for two battleships and four monitors, involving about 6,700 tons of plain steel armor, oil tempered, but it required about two years before the first shipments were made, in 1889.

About 1900 the company also made a valuable contribution to the steel trade by its development of high speed tool steel, which was first exhibited at the Paris Exhibition in 1900, whereby the cutting speed and the size of cut were multiplied many times, as compared with that of the ordinary or special tool steel used theretofore. This tool steel is composed of special alloys and heat treated in a particular manner to produce its best qualities, and since that time it has been improved by constant and intensive study and trials. This has materially speeded up, improved and lowered the cost of all machine tool operations.

About 1906 and 1907 the Bethlehem Steel company built an entirely new steel plant and rolling mills at Bethlehem, for the manufacture of rails and structural shapes of open hearth steel.

The company at that time was the largest producer of open hearth rails. They also at that time pioneered in the development, in this country, of the manufacture of wide-flanged girder sections and H sections for columns, rolled in one piece; this latter work being accomplished on a special type of universal mill. This has added very materially to simplicity in structural design, as the use of such sections eliminates a large amount of fabrication, and provides sections which can be readily used and adapted for all kinds of structures with the minimum amount of work. In addition to this the structural mills produce all sizes of ordinary and standard structural sections, which are used in the construction of all types of buildings, bridges, ships, etc.

Coming down now to later times and to those of the recent World war, the Bethlehem Steel company, together with other companies of these United States, became intensively active in the supplying of materials to the Government and to the Allies, in order to meet the emergency, and as a result immense quantities of material were produced.

SPECIFICATIONS

A few remarks on the history of specifications may be of interest. For quite a number of years after the beginning of intensive steel manufacture in this country, there were, generally speaking, no specifications worth mentioning, and the orders used to read: "Steel for Carriage Tires," "Steel for Wagon Tires," "Steel for Plow Shares," "Blacksmith's Bar Steel for Forging," "Horse-shoe Steel," "Shafting Steel," etc., and the manufacturers were ready and willing to furnish the different grades required, based upon their knowledge of the goods and needs.

Later, the railroads and boiler makers, however, placed certain specifications on their rails, boiler plates, etc., to meet their necessary requirements. This was really the beginning of rigid inspection of steel materials. One of the first railway inspectors with whom the writer was acquainted was Charles L. Taylor, a benefactor of Lehigh University, and a donor of certain buildings on the campus now named for him.

Shortly thereafter, in the early 1880's, one of the first commercial bureaus in this country, for steel inspection, was organized by George W. G. Ferris, the builder of the Ferris Wheel, in

Chicago in 1893, since which time these bureaus have grown and multiplied.

Previously, and at that time one general item of belief was,—that both phosphorus and sulphur were detrimental to steel. Based upon this, the consumers and inspectors of these products began to prescribe less and less of these metalloids, and this has continued to the present time, when the amounts specified are the least practicable, and in some cases less, thus leading to rejections. Only a few years ago a committee of the American Society for Testing Materials was appointed to investigate the deleterious effects of phosphorus and sulphur on steel, and although their work is not yet completed, it shows that the effects of sulphur in amounts somewhat higher than those now generally specified, are not harmful, so that it seems that this has been over-estimated.

With the advance of knowledge and practice in steel making and treating, and use, there is no question whatsoever but that the quality of steel in most respects has improved from year to year since the beginning of this manufacture on a large scale, and although we hear from some customers that “steel is not what it used to be”—we know that, generally speaking, there is more skill exercised now in steel making than there ever has been before in the history of the world, and the product is better and more diversified.

For some of the finer and smaller products, however, this might not be exactly true, if improperly, ordinary steels at ordinary prices are ordered for difficult requirements.

It must also be remembered that as steel has proved itself equal to the tasks set for it, there is a growing tendency on the part of users to expect more and more from it as time passes.

With other natural products, such as timber, coal, stone, etc., users know that they must be content with the qualities that nature provides, and if they select the best of their kinds, they will cost more; but with steel, which is, of course, made from nature's materials, and with human brains and hands, they improperly consider that they can ask for and expect better and better qualities without limit, as their requirements demand. We may be assured, however, that the steel manufacturer is constantly improving his product, and that the qualities are better than ever, for which skilled men like yourselves are in large part responsible.

POSSIBILITIES OF PRODUCING MALLEABLE IRON AND INTERMEDIATE PRODUCTS OF VALUE IN SHORT ANNEALING PERIODS

BY ANSON HAYES AND W. J. DIEDERICHS

Abstract

Laboratory methods for producing malleable iron in 41 hours or less, are outlined in this paper, as well as laboratory methods for producing intermediate products of desirable physical properties. The relations between the method of treatment, microscopic structures and the physical properties are also discussed.

IN A PAPER¹ read before the Detroit meeting of this Society in October, 1922, the results of experiments, the purpose of which, was to shorten the annealing time for the malleablization of white cast iron were given. During the progress of this work intermediate products were obtained which were of considerable interest. The physical properties of the completely malleablized material and some of the intermediate products were reported.

The materials of most interest obtained in this work were first, a good grade of completely graphitized iron produced in 45 hours, and second, some intermediate products whose tensile properties ran as high as 84,000 pounds per square inch and 6 per cent elongation.

The object of the present paper is to report the results of further experimental work, the purpose of which was to further shorten the annealing cycle for complete graphitization of white iron. Also, it was desired to more carefully study the conditions for the production of intermediate products, to develop new intermediate products and to further investigate their physical properties.

¹Hayes and Diederichs, TRANSACTIONS, American Society for Steel Treating, March, 1923, page 624.

The authors wish to acknowledge their indebtedness to the Iowa Malleable Company of Fairfield, Iowa, who so kindly furnished the white iron used in these experiments; to H. E. Flanders, graduate student in physical chemistry, who made the photomicrographs; and to E. T. Tran of the Park Drop Forge Company of Cleveland, who so kindly made the Izod tests.

A paper presented by Dr. Anson Hayes before the Spring Sectional Meeting of the Society, Moline, Ill., May 23, 1924. Of the authors, Dr. Hayes is professor of physical chemistry and metallography; W. J. Diederichs is associate professor of mechanical engineering, Iowa State College, Ames, Iowa.

The following Table I shows that the white iron used in all of the experiments reported in this paper was of normal composition.

Table I					
Material	Silicon	Sulfur	Phos.	Mn.	Total Carbon
White cast iron...	0.94	0.037	0.166	0.26	2.23

SHORTENING THE CYCLE FOR COMPLETE GRAPHITIZATION

Our previous work² showed that it required about 3 hours at 1700 to 1800 degrees Fahr. to completely absorb massive cementite. This work also showed that the absorption of this cementite was much slower at the lower temperatures used in the commercial process. It is essential that all massive cementite be absorbed before cooling starts, and that the cooling be so regulated that no grain-boundary cementite will be precipitated as the temperature falls to that of the lower critical. Having eliminated all free cementite for all temperatures above the critical, a further condition for obtaining complete graphitization is that the rate of cooling through the critical (the iron-carbon eutectoid) be retarded sufficiently to avoid the formation of pearlite. It is well known that this final cooling rate is 10 or 11 degrees Fahr. per hour as a maximum.

With these facts in mind the following treatment was used for shortening the cycle for complete graphitization. Ten standard 5/8-inch tensile test bars were placed on end, unsupported and unpacked, in an L & N hump furnace whose temperature was 1700 degrees Fahr. The temperature dropped to 1200 degrees Fahr. and it required 40 minutes for it to again reach 1700 degrees Fahr. This temperature was maintained for 3 hours and it was then lowered to 1560 degrees Fahr. in 1 hour. Then the cooling rate was reduced so that the bars cooled uniformly and slowly to 1320 degrees Fahr., requiring 14 hours, (rate 17 degrees Fahr. per hour). At this time the rate was further reduced to 10 degrees Fahr. per hour so that the bars cooled to 1200 degrees Fahr. in an additional time of 12 hours. The process was considered complete when 1200 degrees Fahr. was reached and it will be noted that the complete overall time required was within 31 hours.

²Hayes and Diederichs, TRANSACTIONS, American Society for Steel Treating, March, 1923, page 624.

It has been shown³ that the carbon-iron eutectoid for white cast iron lies at 1420 degrees Fahr. and that it is easily undercooled to about 1320 degrees Fahr. Therefore in the above experiment, the 10 degrees Fahr. cooling rate was not used until a temperature of 1320 degrees Fahr. had been reached.

Three of these bars were tested and gave the results shown in Table II.

Table II

Tensile Strength	Yield Point	Elongation
Lbs. per sq. in.	Lbs. per sq. in.	% in 2 inches
48,000	30,200	14
45,500	30,400	11
48,200	31,900	12

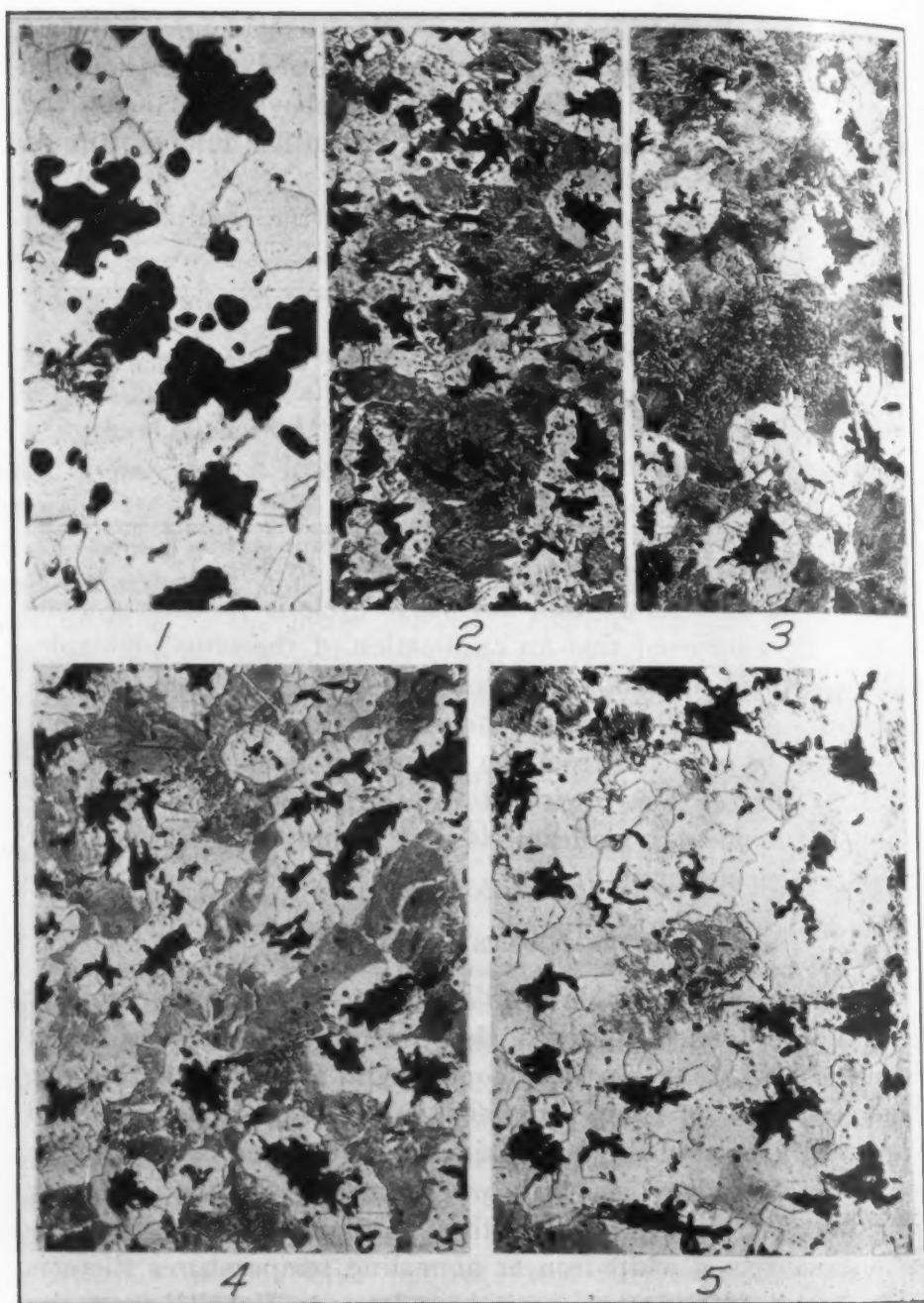
That graphitization is completed is shown by Fig. 1.

It has not been shown that the above cycle is the shortest one possible. It is believed that an application of the same principles as above outlined will allow a more rapid cooling between the high temperature and 1560 degrees Fahr. Also it is almost certain that material can be removed from the furnace at temperatures higher than 1200 degrees Fahr. without interfering with the resulting properties. A one-day malleable is well within the possibilities of laboratory demonstration.

INTERMEDIATE PRODUCTS

It is considered desirable at this point to state rather carefully the principles which underlie the control of properties when graphitization is only partially completed. It is known that the effective strength of grain-boundary cementite in hyper-eutectoid steel is very low, probably approximating 5000 pounds per square inch. Grain-boundary cementite when present, also tends sharply and radically to reduce the ductility. As long as massive cementite is present in a white-iron at annealing temperatures there is always grave danger that grain-boundary or "shell"-cementite will form during the subsequent cooling. It is imperative therefore, that the high temperature be maintained until all massive cementite is absorbed and further, the cooling down to the critical point must be so regulated as to avoid the formation of shell-

³Hayes, Flanders and Moore, TRANSACTIONS, American Society for Steel Treating, Vol. V, page 184.



Photomicrographs Showing the Structures Obtained During Malleabilization of White Cast Iron When Subjected to Various Treatments for Varying Time Intervals. Magnification 100 Diameters. For Treatments, See Table III.

cementite. This is necessary if materials having tensile properties of any commercial promise are to be obtained.

It is evident from the foregoing that combined carbon in excess

of that necessary to form pearlite, will result in undesirable physical properties. It is known that in steels of normal structure the strength increases as the carbon increases until a structure of one hundred per cent pearlite is attained. When this point is reached, a value of 125,000 pounds per square inch results, and although the ductility decreases with carbon increase, a pearlitic steel retains 10 per cent elongation. It would be expected, therefore, that a material of maximum possible strength would be obtained from white cast iron if the graphitization proceeded only until a pearlitic matrix resulted, and moderate elongations would still be retained. This material would then consist of pearlite containing about 10 per cent by volume of temper-carbon, and the resulting properties would approach those of pure pearlite. If the graphitization is carried beyond this point, the strength should progressively decrease, and the ductility should progressively increase until they attain values as found in normal malleable iron. It should be recognized, of course, that we are here dealing with a cast material which has not been mechanically worked, as is the case in steels whose properties we have quoted. Matrix structures in treated cast irons might be expected to very nearly duplicate the physical properties of the same structures in cast steels.

In Table III is tabulated the properties of products obtained by five treatments. It is to be noted in the accompanying photomicrographs that in every case the graphitization was carried to such a point that a hypo-eutectoid matrix resulted. The treatment previous to reaching the eutectoid temperature, though varied, was such as to insure the elimination of any free cementite. The data of Table III are arranged in order of cooling rates employed in carrying the material through the eutectoid range. It is evident from the figures that as the cooling rate decreases, the pearlite in the matrix also decreases until in the case of a 10 degrees Fahr. per hour cooling rate, all combined carbon has been eliminated. Attention is called to the continuous variations in tensile properties and the overall time for their production. It will be noted that in an overall time of $10\frac{1}{2}$ hours a material has been produced which meets the specifications of the American Malleable Iron association. As the cooling rate in these treatments increased, the tensile properties varied from those of malleable iron, to values of about 70,000 pounds per square inch strength and 4 per cent

elongation. When the treatment was regulated so that the carbon concentration in the solid solution was such that a normal pearlite matrix with very little free ferrite resulted on cooling through the eutectoid range, the tensile strength values increased to 80,000 to

Table III

Treatment	Overall Time Hrs.	Tensile Strength, Lbs per Sq. In.	Yield Point (By Dividers) Lbs. per Sq. In.	Elongation Per Cent in 2 Inches	Impact Values (Izod) Ft.-Lbs.	Structure See Fig. Below	Remarks
3 Hrs. at 1700° F. cool to 1560° F. in 45 Min. 3 Hrs. at 1560° F. cool to 1200° F.; cooling rate of 6½° F. per Min.	8	74,400 67,800 67,500	49,000 49,000 43,500	4 3½ 5½	8 8 8	Fig. 2	Impact tests were on bars from the same heat but not on the same bars as used for tensile test. Tensile Tests run on bars as cast.
3 Hrs. at 1800° F. cool to 1650° F. in 45 Min. 3 Hrs. at 1650° F. cool to 1200° F.; cooling rate of 5° F. per Min.	9	69,000 67,000 72,500	49,500 44,500 47,500	4½ 4½ 5½	8 10 8	Fig. 3	
3 Hrs. at 1800° F. cool to 1560° F. in 1 Hr. 20 Min. 6½ Hrs. at 1560° F. cool to 1260° F.; cooling rate of 40° F. per Min.	13	69,250 68,750 60,380	45,000 45,600 45,500	6 5½ 6	8 8 8	Fig. 4	
3 Hrs. at 1800° F. cool to 1650° F. in 1 Hr. 3 Hrs. at 1650° F. cool to 1200° F.; cooling rate of 3° F. per Min.	10½	53,500 56,600 57,600	36,600 36,100 38,200	9 8½ 10	8 8 8	Fig. 5	
3 Hrs. at 1700° F. cool to 1560° F. in 1 Hr. cool to 1320° F.; rate 17° 1 Hr. cool to 1200° F.; rate 10° 1 Hr.	31	For Comparison 48,000 45,500 48,200		30,200 30,400 31,900	14 11 12	Fig. 1	
Impact test on Malleable from same Pour Annealed with Commercial Run of Work					14 15 18		

85,000 pounds per square inch with 5 to 6 per cent elongation.⁴ The first treatment cited in Table III shows lower strength than this, because graphitization had progressed so far that large amounts of free ferrite had been formed, and the elongation values

⁴Hayes and Diederichs, TRANSACTIONS, American Society for Steel Treating, March, 1923, page 629, Treatment F.

were also somewhat lower because a cooling rate of 5 or 6 degrees Fahr. per minute was too rapid to allow the formation of truly normal pearlite.

There is a general rule known to hold for all normal iron-carbon alloys, and that is that the yield point has a value of about $\frac{2}{3}$ of the tensile strength. Any of the products here presented conform very closely to this rule. The yield points obtained are of the same order of magnitude as those found in normal steels of the same combined carbon content. For example, Langenberg⁵ gives for a normalized cast steel of 0.3 per cent carbon a value of about 47,000 pounds per square inch, and Stoughton⁶ gives a table for worked steels in which the elastic limit of 40,000 pounds per square inch is given for 0.4 per cent combined carbon, and 38,000 pounds per square inch for 0.3 per cent combined carbon.

The Izod impact tests on these intermediate products of annealing gave results which remained practically constant at 8 foot-pounds regardless of the treatment. It is obvious that this value is sharply doubled when complete graphitization has been accomplished. It is of interest to note, however, that this impact value compares very favorably with values for normalized cast steel as given by Langenberg.⁷ He gives a Charpy impact value of 11.32 foot-pounds for a cast steel of 0.3 per cent carbon. He further gives values for normalized forged steel which shows that the impact value decreases rapidly as the combined carbon content increases. For a steel of 0.32 per cent carbon a value of 15.2 foot-pounds is given, and for a carbon content of 0.46 per cent the value is 7.99 foot-pounds.

It is agreed that comparisons between Charpy and Izod impact values are rather difficult to make. Ordinarily, however, the Charpy values run somewhat higher than Izod values when comparative tests are made. It would seem therefore that these comparisons are legitimate. Reference is made to the work of Dix.⁸

There has been occasion for machining these intermediate products both on a lathe and on a milling machine and they presented no difficulty. The surface produced, very closely resembles that of machined steel.

⁵*Proceedings, American Society for Testing Materials*, Vol. 21 (1921), page 848.

⁶*Metallurgy of Iron and Steel*, McGraw-Hill Co., 1923, page 341.

⁷*Proceedings, American Society for Testing Materials*, Vol. 21 (1921), page 848 and 849.

⁸*Proceedings, American Society for Testing Materials*, Vol. 19, part 2 (1919), page 843.

Table VII.

It would seem that a cast iron which by a short treatment can be given properties such as reported, should find commercial uses as a substitute for malleable iron and steels for certain purposes. The yield point, that strength characteristic upon which design is based, is as high as that for normal steels of the same combined-carbon content, and is superior to that of malleable iron. The shock resistance is comparable to that of steel and though less than that of malleable iron would seem to be ample for many purposes. The ductility also would seem to be ample to allow for the slight changes in shape sometimes required in assembling and similar operations.

As an example of possible commercial uses let us consider the ordinary malleable link chain and sprocket wheel. This chain frequently gives difficulty due to stretching and riding the sprockets, and due to wear on both sprocket and link the same difficulty ensues. It is believed that these parts made of the same weight of material, such as these reported, having about 40 per cent higher yield point and a greater wearing resistance due to the presence of pearlite in the matrix, would largely eliminate the difficulty. These intermediate products seem to offer possibilities of reducing the weight or the cost, or both, of many designs now employing malleable iron or steel.

CONCLUSION

It is fully realized that the treatments here given differ from those used commercially. Somewhat higher temperatures are used, more rapid temperature changes are involved and the use of a packing material is eliminated. These changes are considered necessary in order to realize the short annealing periods obtained in these experiments. Dispensing with a packing material necessitates the substitution of a suitable furnace atmosphere and a study of the effect of atmosphere upon the resulting products. This study is in progress. It has already been observed that the elimination of a packing material and the accompanying weight seems to have very largely done away with warping.

It is believed that the employment of a suitable atmosphere with a traveling hearth furnace offers possibilities of making these laboratory treatments commercially feasible.

COMPARISON OF BRINELL AND ROCKWELL HARDNESS OF HARDENED HIGH SPEED STEEL

BY S. C. SPALDING

Abstract

In this paper the author has compared the hardness of high-speed steels as measured by the Brinell and Rockwell hardness testers.

The steels were treated under varying temperatures and both the Rockwell and Brinell hardness numbers were obtained. These are tabulated and shown in the accompanying curves.

THE WORK described in this paper was undertaken with the idea of comparing the hardness of hardened high speed steel as measured by the Rockwell hardness tester, with the hardness obtained by the standard Brinell method.

PROCEDURE

The steels used were of the 16 to 18 per cent tungsten type, with some variations in the carbon, chromium and vanadium contents. The aim was to harden all samples at a constant temperature of 2300 degrees Fahr., then draw back at variable temperatures. The samples themselves were pieces $\frac{1}{2}$ to $\frac{5}{8}$ inches long, sawed from $1 \times \frac{5}{8}$ inch bars. In hardening, all the samples from any one steel were placed on a pan, then put into the preheating furnace. Later the pan and all were transferred to the high heat furnace, from which they were quenched in oil. This was done to insure an identical hardening on all samples from any one steel. The drawing was done in liquid baths; oil, salt, or lead being used.

The drawing temperatures were maintained for 30 minutes at temperature. The hardness tests were all made on the sawed ends of the pieces, so as to eliminate any effect of the bark which might have been on the surface of the bars. The ends were ground

A paper presented before the Sixth Annual Convention of the Society, held in Boston, September 22 to 26, 1924. The author, S. C. Spalding, is metallurgist with the Halcomb Steel Co., Syracuse, N. Y.

smooth and brought to a high polish, so that the Brinell impressions could be read at 50 diameters on the ground-glass of the metallographic microscope.

RESULTS OBTAINED

The data obtained can be tabulated as follows:

Chemical Analysis and Heat Treatment					
	Bar 693 Per Cent	Bar 1734 Per Cent	Bar 1732 Per Cent	Bar 1742 Per Cent	Bar 1738 Per Cent
Carbon	0.49	0.57	0.65	0.72	0.74
Chromium	2.75	2.90	3.08	3.84	3.00
Tungsten	16.18	15.70	16.24	18.48	16.38
Vanadium	1.13	1.07	1.08	1.31	0.99
	Treatment degrees Fahr.	Treatment degrees Fahr.	Treatment degrees Fahr.	Treatment degrees Fahr.	Treatment degrees Fahr.
Preheat	1750	1750	1750	1700	1750
High Heat	2300-3½ Min.	2280-4½ Min.	2280-4½ Min.	2330-2½ Min.	2260-6½ Min.

Hardness Tests										
Reheat Temp. degrees Fahr.	BRINELL					ROCKWELL C SCALE				
	Bar 693	Bar 1734	Bar 1732	Bar 1742	Bar 1738	Bar 693	Bar 1734	Bar 1732	Bar 1742	Bar 1738
None	600	652	677	658	658	59	63	65	64	65
300	600	658	677	652	658	57	63	65	62	64
600	591	617	617	632	617	57	59	61	60	61
800	582	605	627	637	622	57	59	60	60	61
900	600	600	632	647	642	57	59	61	60	62
1000	606	627	632	652	658	58	61	62	62	63
1100	596	617	642	647	647	57	61	61	60	61
1200	555	596	605	591	623	54	57	58	56	59
1300	502	528	520	441	541	50	52	54	46	54
1400	325	402	380	364	375	36	37	43	40	43
1500	298	332	356	340	364	32	36	40	39	42

Six curves, Figs. 1, 2, 3, 4, 5 and 6, have been plotted from the data sheets, including a curve of Brinell versus Rockwell. If the actual points are followed a broken curve results. However, a straight line seems to represent the average. The curves for Brinell and Rockwell hardness on the individual steels indicate that both instruments are affected in the same proportion by the property of the steel designated by the term hardness. The Rockwell tester, while it offers, perhaps, a more convenient way of testing than the Brinell, does not give any additional information regarding the hardness of the metal.

The temperature of maximum secondary hardness, as found by both the Rockwell and the Brinell in this investigation, occurred at 1000 degrees Fahr. The value of the hardness at 1000 degrees Fahr., determined by Brinell test, in some cases equals that at

no-draw and in some cases is a trifle lower. The Rockwell hardness at 1000 degrees Fahr. is in every case a trifle lower than at no-draw.

Similar investigations by others indicates that in some instances the temperature of maximum secondary hardness is at 1000 de-

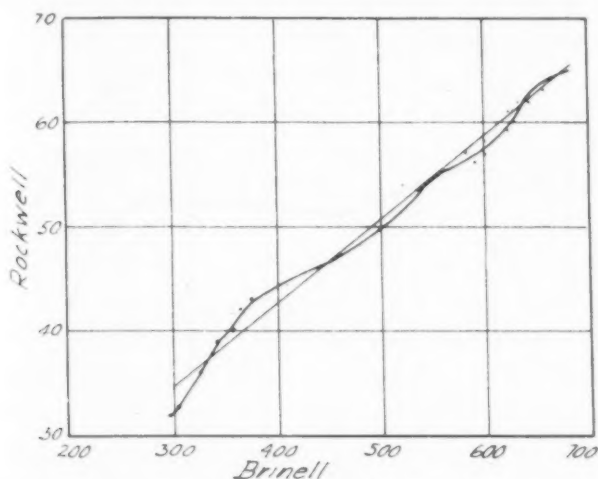


Fig. 1—Curve Showing Rockwell verses Brinell Hardness Numbers.

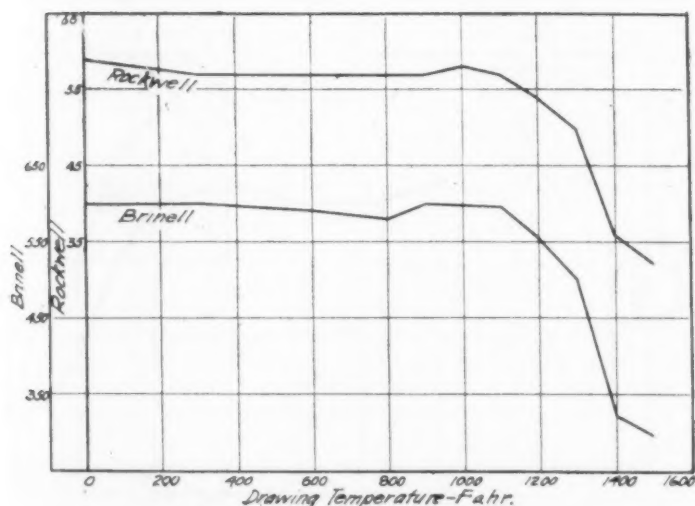


Fig. 2—Measurements of Hardness of Quenched High Speed Steel Drawn at Varying Temperatures, Bar No. 693, Analysis: Carbon 0.49, Chromium 2.75, Tungsten 16.18 and Vanadium 1.13.

grees Fahr., in others at 1100 degrees Fahr. The hardness values found at the maximum secondary point have sometimes been equal to and more often greater than the initial hardness before the draw.

There seems to be a variation in the results of different investigators, which may possibly be due to differences in the initial hardening temperatures and times.

Reviewing briefly the work of some of the other investigators,

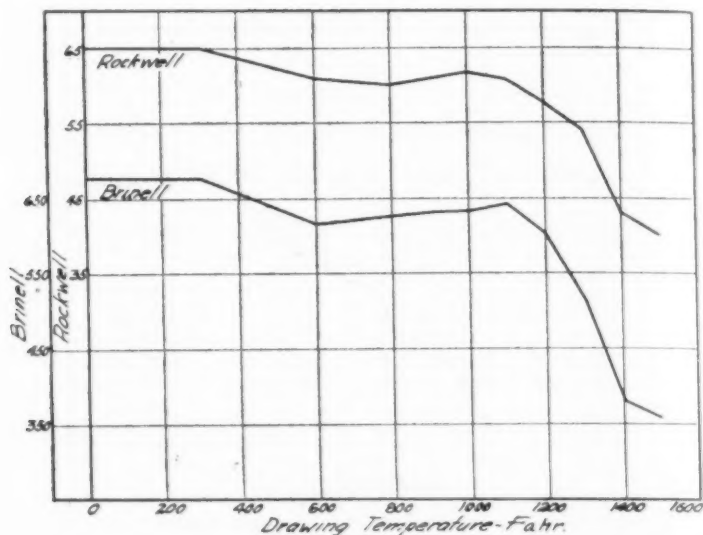


Fig. 3—Measurements of Hardness of Quenched High Speed Steel Drawn at Varying Temperatures. Bar No. 1732, Analysis: Carbon 0.65, Chromium 3.08, Tungsten 16.24 and Vanadium 1.08.

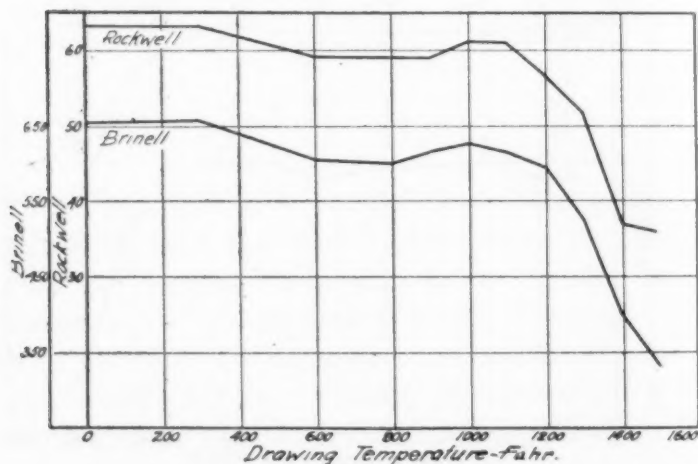


Fig. 4—Measurements of Hardness of Quenched High Speed Steel Drawn at Varying Temperatures. Bar No. 1734, Analysis: Carbon 0.57, Chromium 2.90, Tungsten 15.70 and Vanadium 1.07.

we find in TRANSACTIONS, Volume 1, page 716, D. M. Giltinan, U. S. Naval Ordnance Plant, Charleston, West Virginia, a curve on high speed steel, where the maximum secondary hardness oc-

curs at 1000 degrees Fahr. Howard Scott, in Bureau of Standards paper No. 395, shows the maximum point to occur at 1100 degrees Fahr. French and Strauss, TRANSACTIONS, Volume 2, page 1125,

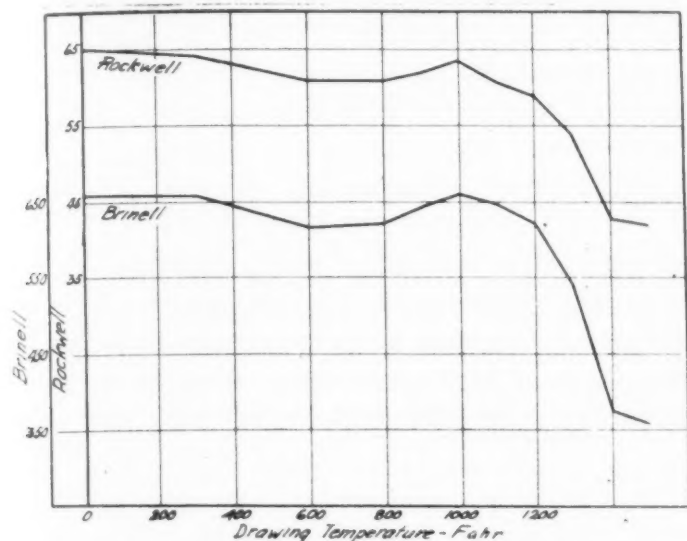


Fig. 5—Measurements of Hardness of Quenched High Speed Steel Drawn at Varying Temperatures. Bar No. 1738, Analysis: Carbon 0.74, Chromium 3.00, Tungsten 16.58 and Vanadium 0.99.

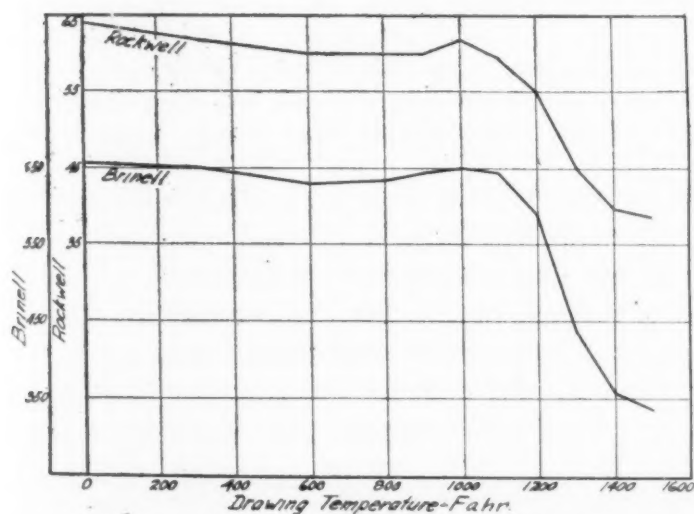


Fig. 6—Measurements of Hardness of Quenched High Speed Steel Drawn at Varying Temperatures. Bar No. 1742, Analysis: Carbon 0.72, Chromium 3.84, Tungsten 18.48 and Vanadium 1.31.

investigating a large variety of high speed steels of standard and special analyses, found in general that the maximum occurs at 1100 degrees Fahr., with a 2415 degrees Fahr. hardening tempera-

ture. Hardening at 2300 degrees Fahr. gives a temperature at which maximum secondary hardness occurs at 1000 degrees Fahr. Hardening at 2150 degrees Fahr. gives a temperature for the maximum secondary hardness, varying from 950 to 1100 degrees Fahr. Gill and Bowman, TRANSACTIONS, Volume 2, page 184, using a hardening temperature of 2350 degrees Fahr., find the maximum secondary hardness to occur at 1100 degrees Fahr.

CONCLUSION

The work reported in this paper was undertaken more with the idea of getting a comparison of Brinell and Rockwell hardness values of high speed steel than as an investigation of the secondary hardness phenomena of high speed steel. Considered in the light of Rockwell versus Brinell, it is believed the data may be of value.

THE PHOTOELASTIC METHOD FOR THE DETERMINATION OF CAUSES OF FAILURE OF METAL STRUCTURES

BY PAUL HEYMANS, G. R. BROPHY AND A. L. KIMBALL, JR.

Abstract

This paper embodies some of the results obtained by the authors through the scientific study of the stresses set up in metal structures, resulting from design and method of installation or assembly. This investigation applies specifically to the study of pinion gears. A brief description and discussion of the photoelastic method of stress analysis is incorporated with reference to previous work done by the authors.

Through the use of polarized light and transparent replicas of the gears under investigation, it has been shown that a gear pinion is weaker than a plain circular ring whose outside diameter is equal to the root diameter of the tooth. It has also been shown that the highest concentration of stress when the pinion is put under uniform radial pressure, is beneath the center of the tooth. That is, the greatest stress concentration is at the point of the heaviest section of the metal, rather than in the thinnest section between the teeth.

As a result of the photoelastic method of analysis, predictions as to the form of failures were made and then substantiated by actual tests with steel gears.

METALLURGICALLY, a steel part may be in excellent condition and capable of a long and satisfactory life, but due to ignorance or carelessness in assembly, may fail prematurely in service. An illustration of this, as the work described in this paper will show, is the method sometimes used in mounting railway motor pinions. The pinion is heated in boiling water to expand it, and then is placed upon the tapered motor shaft and driven home

Acknowledgment is made to the General Electric Company for their courtesy in supplying the color plate, Figs. 2, 3, 4, and 5, reproduced from autochrome photographs made of transparent replicas of gear pinions subjected to various pressures, through which plain polarized light was passed.

A paper presented before the Winter Sectional Meeting of the Society, Rochester, N. Y., Jan. 31, 1924. Of the authors, Paul Heymans is assistant professor of physics, Massachusetts Institute of Technology, Cambridge, Mass., G. R. Brophy and A. L. Kimball, Jr., are associated with the Research Laboratory, General Electric Co., Schenectady, N. Y.

by several heavy blows of a sledge hammer. This sets up stresses within the pinion that are not allowed for in the calculation and the design, and may be one of the big factors in early failure.

In a paper presented before the American Society of Mechanical Engineers, December, 1922, P. Heymans and A. L. Kimball, Jr.,¹ reported the results of their studies of the distribution of stress in celluloid models of pinions, by means of the photoelastic method.

In view of the results of the present investigation, the ordinary methods of stress calculation in gear teeth should not be expected to give reliable and complete information even as to static stress distribution. Indeed, the shape of the tooth, the fillet at the root, the ratio of the diameter of the pinion bore to the root diameter and outside diameter, and the stresses introduced by the placing of the pinion on the shaft, all affect the static stress distribution and the maximum stress.

Detailed photoelastic analyses of the stress distribution for different gear pinions under different loading conditions (radial shrinking pressure and static torque), are given in the paper mentioned. Analyses of the dynamic stresses, upon which a later preliminary report was presented before the American Society of Mechanical Engineers,² is being continued in the light of the previous photoelastic analyses and some recent theoretical considerations.³

Some especially interesting results, as verified by mechanical tests, are presented.

STRESS ANALYSES AND MECHANICAL TESTS UNDER RADIAL SHRINKING PRESSURE ONLY

When a circular ring is shrunk onto a shaft, the stresses set up in the ring can be obtained mathematically. The following relations express, at any point at a distance r from the center, the radial and tangential stress $\hat{r}r$ and $\hat{\theta}\theta$ as multiples of the inside

¹P. Heymans and A. L. Kimball, Jr., "Stress Distribution in Electric Railway Motor Pinions as Determined by the Photoelastic Method," *Transactions of the American Society of Mechanical Engineers*, 1922.

²P. Heymans and A. L. Kimball, Jr., "Stress Distribution in Rotating Gear Pinions as Determined by the Photoelastic Method," *Mechanical Engineering*, March, 1924.

³P. Heymans, "The Mathematical Theory of Dynamic Stresses in Gear Pinions," presented at the spring meeting of the American Society of Mechanical Engineers, 1924.

radial pressure P , which may readily be derived from the thermal expansion of the material,

$$\begin{aligned}\hat{r}r &= P \frac{r_1^2 (r^2 - r_2^2)}{r^2 (r_1^2 - r_2^2)} \\ \Theta\Theta &= P \frac{r_1^2 (r^2 + r_2^2)}{r^2 (r_1^2 - r_2^2)} \\ \hat{r}r_{\max} &= -P \quad (\text{at } r = r_1) \\ \Theta\Theta_{\max} &= P \frac{2}{1 - \left(\frac{r_2}{r_1}\right)^2} \quad (\text{at } r = r_2)\end{aligned}\tag{1}$$

where r_1 and r_2 are the inside and outside diameters respectively.

It is seen from equations (1) that for the same bore r_1 , when the outside diameter r_2 of the ring is increased, the stresses decrease.

A gear pinion might be considered as a circular ring of an outside diameter equal to the root diameter of the pinion reinforced by a certain amount of material, but without enough to form a complete ring whose outside diameter equals the outside diameter of the pinion. Following this analogy, it was believed that the stresses in gear pinions, due to shrinking them on their shaft, were intermediate between the stresses mathematically obtained for two rings whose outside diameters are respectively equal to the root diameter of the tooth and to the outside diameter of the pinion, the inside diameter being for both the diameter of the bore of the pinion.

From the authors' previous experience regarding stress concentrations resulting from irregular boundaries, it was suspected that the maximum stress in the pinions under a given radial deformation would be greater than the maximum stress not only in the larger, but also in the smaller ring. The photoelastic analyses showed that the gear pinion is weaker than the plain circular ring whose outside diameter is equal to the root diameter of the tooth. The change of external profile, due to the presence of the teeth, although constituting an addition of material, weakens the structure.

Figs 2, 3, 4 and 5 are reproductions of autochrome photographs made in the photoelastic analysis of pinions subjected to

different degrees and types of stress. Fig. 2 shows that the highest concentration of stress, when the pinion is put under uniform radial pressure, is beneath the center of the tooth, in the heaviest section of metal, rather than in the thinnest section between teeth. The third order of blue, shown in this Fig. 2 beneath

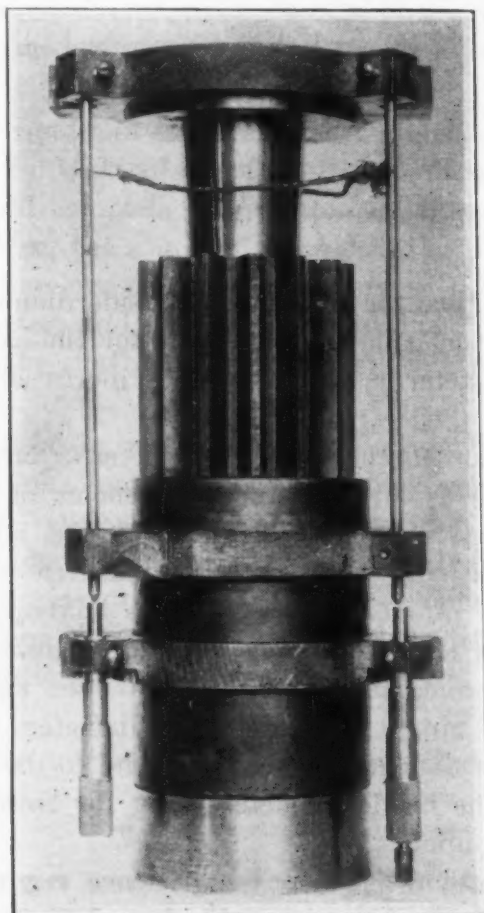


Fig. 1—Showing the set-up and method of forcing a tapered plug into the tapered bore of steel rings and steel pinions. The axial pressure of the plug was recorded.

the center of the tooth at the inside radius of the pinion, is the photoelastic evidence of this stress concentration.

Mechanical tests on steel rings and steel pinions were made subsequent to these photoelastic tests.

A tapered plug was forced into the tapered bore of steel rings and steel pinions, as shown in Fig. 1, and the axial pressure on the plug was recorded. In Table I the dimensions of the rings and the rupture loads for rings and pinions are given.

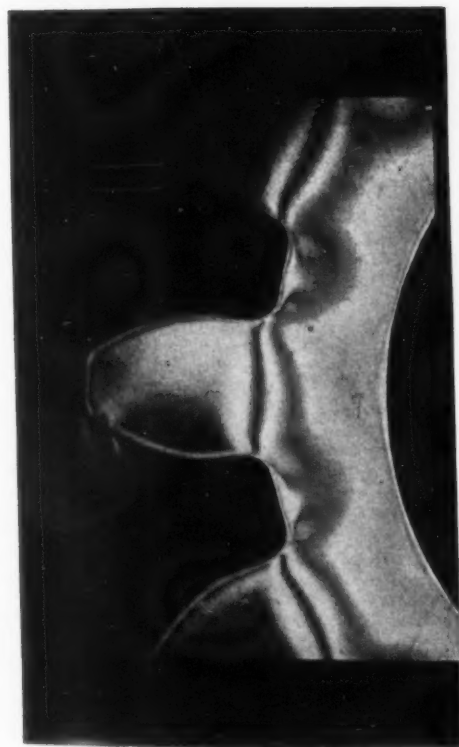


FIG. 1. COLORED IMAGE WHEN NORMAL INSIDE PRESSURE ALONE IS APPLIED



FIG. 5. COLORED IMAGE OBTAINED FOR NORMAL INSIDE PRESSURE AND REDUCED TORQUE

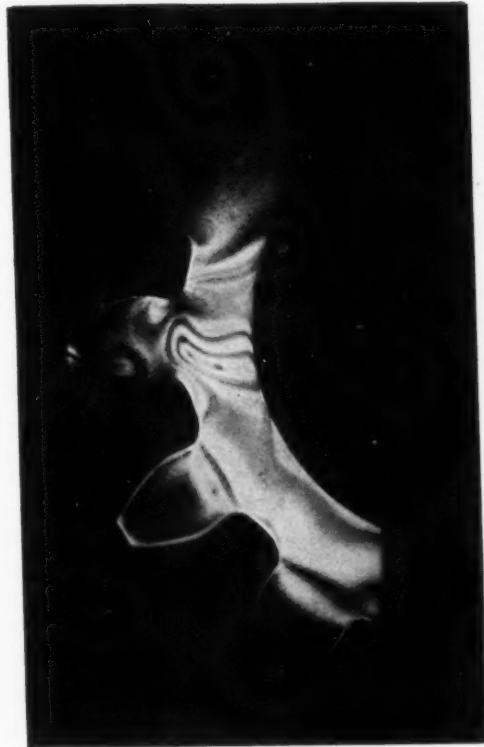


FIG. 6. COLORED IMAGE WHEN BOTH NORMAL INSIDE PRESSURE AND MAXIMUM TORQUE ARE APPLIED

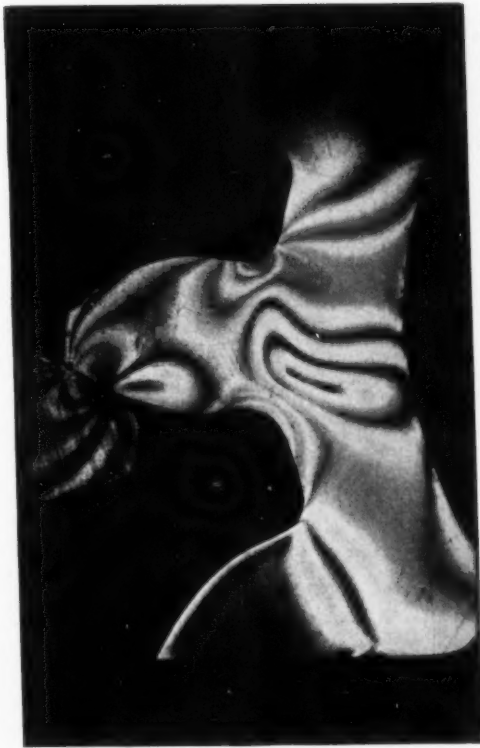


FIG. 6. COLORED IMAGE WHEN BOTH NORMAL INSIDE PRESSURE AND MAXIMUM TORQUE ARE APPLIED



This table shows that the load necessary to rupture the pinion was smaller than the load required for the rings.

Fig. 6 is a photograph of the ruptured pinions, showing that the fractures in the pinions all started directly beneath the center

Table I
Rupture Load on Arbor Forced into Specimens Tested

	Inside Diam. (inches)	Outside Diam. (inches)	Root Diam. (inches)	Rupture Load (pounds)
--	--------------------------	---------------------------	------------------------	--------------------------

Ring -----	1.854	3.5		85,000
Ring -----	1.854	2.5		51,000
Pinion* -----	1.854	3.5	2.5	47,000

*12 teeth, $4\frac{1}{4}$ diameter pitch, 20 degrees involute, Brown-Sharpe proportions.

of a tooth and usually, contrary to expectation, passed through the tooth.

As teeth are removed, the pinion approaches again the condition of a circular ring and the same shrinking pressure should set up lower maximum stresses. A remarkable verification of this was found in the course of the mechanical tests described later in the paper.

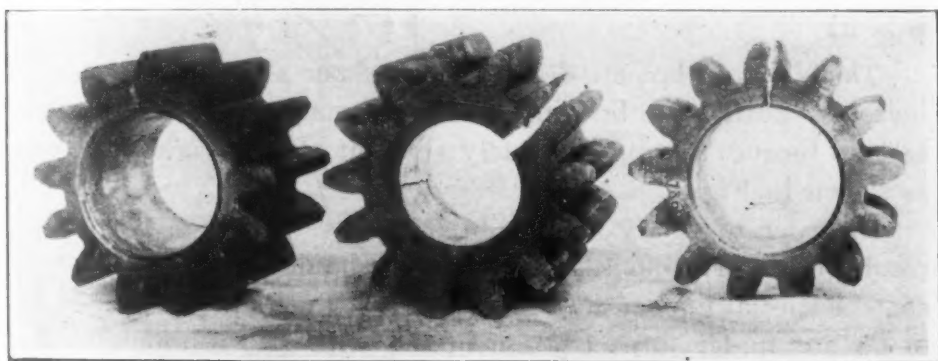


Fig. 6—Pinions ruptured by being forced on tapered plug.

STRESS ANALYSES AND MECHANICAL TESTS UNDER COMBINED RADIAL PRESSURE AND STATIC TORQUE

Figs. 3, 4 and 5 show the images obtained in the photoelastic analyses of the gear pinions under combined radial pressure and static torque.

The photoelastic analyses⁴ revealed that the sections of dangerous stresses are different for different values of the radial pressure and the applied torque load and that, as a result of highly

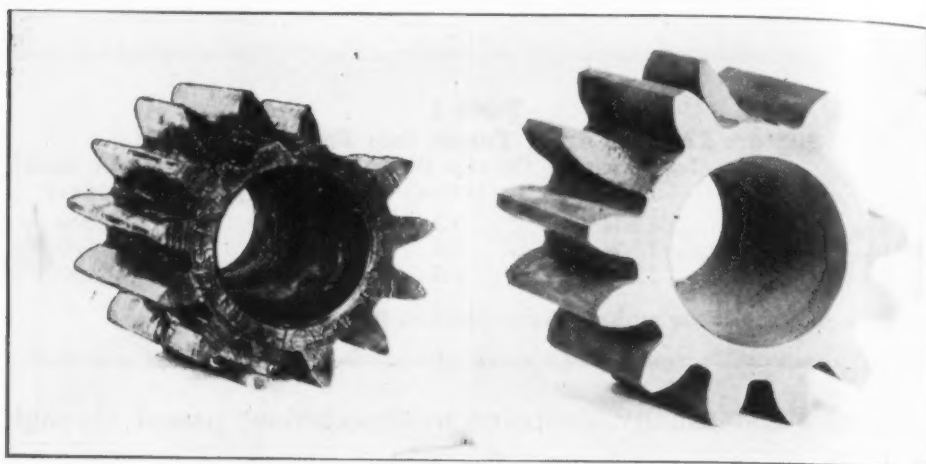


Fig. 7

Fig. 8

Fig. 7—Shows V-shape rupture of a pinion tooth having a high radial pressure and torque load. Fig. 8—Shows the fracture of a pinion with no radial pressure. The absence of the V-shape notch is conspicuous.

localized stresses, a pinion under a high radial pressure and torque load would fracture as shown in Fig. 7, with a V-shape, whereas the fracture of a pinion with no radial pressure is as shown in Fig. 8.

The V would become deeper and sharper as the radial pressure increases until, as a limiting case, with maximum radial pressure and no torque, an approximately straight radial crack is obtained as shown in Fig. 6.

In order to verify and to further investigate the photoelastic results on steel pinions, a series of mechanical tests were carried out. A special impact machine was built which allowed the pinions to be put under impact-fatigue tests, with and without internal radial pressure, to approximate service conditions. Fig. 9 shows a sketch of the machine.

The pinion is supported by two teeth in a jig or anvil. The blow is delivered on one end of a tooth, through a hardened steel pin, normal to the tooth profile, by a 32-pound weight falling through a height of 12 inches. The pin is in contact with the tooth face along a 1-inch line parallel to the base of the tooth and about $\frac{1}{8}$ inch from the top of the tooth, or between the outside diameter

⁴P. Heymans and A. L. Kimball, Jr., loc. cit., December, 1922.

and the pitch line. The weight is raised by a rotating arm operated by a $\frac{1}{2}$ -horsepower motor.

When a tooth breaks, the weight falls an additional $\frac{1}{8}$ inch and allows an arm attached to the weight to come in contact with a button switch which breaks the circuit and stops the machine.

Fig. 10 shows the fractured teeth of a series of pinions tested by repeated impact. The first tooth on the left shows a concave

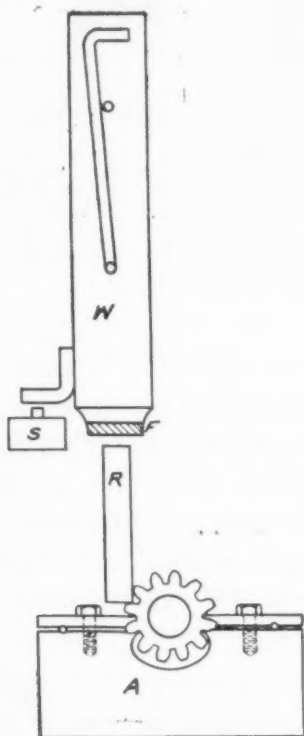


Fig. 9—Diagrammatic sketch of special impact testing machine used for subjecting pinions to impact fatigue tests, with and without internal radial pressure. A, anvil, R, hardened steel pin, S, automatic switch, W, 32-pound weight, and F, hardened face.

fracture which is typical for pinions broken by repeated impact with no radial pressure. The second tooth shows a slightly convex fracture. This tooth was broken from a pinion having radial pressure resulting from forcing the tapered plug into the bore with a load of 5000 pounds. The third tooth is from a pinion, the plug pressure of which was 10,000 pounds; the fourth, 25,000 pounds; and the last 40,000 pounds.

As predicted from the photoelastic analyses, the fractured sur-

face of the tooth changes from concave to convex with increasing bore pressure and the convexity becomes greater until the yield point of the pinion is reached.



Fig. 10—Shows the fractured teeth of a series of pinions tested by repeated impact. Tooth No. 1 shows a concave fracture typical of pinions broken by repeated impact, having no radial pressure; tooth No. 2 shows a slightly convex fracture resulting from a pinion having a radial pressure, resulting from forcing a plug into the bore with a load of 5000 pounds; tooth No. 3 shows a gear tooth having double the radial pressure of tooth No. 2; tooth No. 4 shows a tooth broken from a pinion having had a radial pressure five times that of tooth No. 2; and tooth No. 5 is that broken from a gear having had eight times the radial pressure of tooth No. 2. It will be noted that the convex type of fracture increases as the radial load is increased.

The curves of Fig. 11 show the results of the impact fatigue tests made on two series of pinions with stressed bores.

The upper curve represents the resistance of 0.42 per cent carbon steel pinions which were first normalized by heating to 900 degrees Cent. (1652 degrees Fahr.) and oil quenching followed by reheating to 760 degrees Cent. (1400 degrees Fahr.) water quenching and drawing at 200 degrees Cent. (392 degrees Fahr.). The Brinell hardness is 555.

As the plug pressure increases, the resistance of a tooth to fracture under repeated impact decreases very rapidly, reaching a minimum strength and then, strangely, the resistance increases to a maximum which occurs when the pinion is under a plug-pressure corresponding nearly to the yield point. Beyond the yield point, results vary widely, but seem to follow a regular order as indicated by the lower curve.

This lower curve shows the results obtained with a series of pinions made from practically the same steel but with a simple hardening treatment consisting of water quenching from 810 degrees Cent. (1490 degrees Fahr.) and drawing at 200 degrees Cent. (392 degrees Fahr.). The Brinell hardness is 512.

The yield points of the pinions were determined by inserting a well-fitted tapered plug into the bore and measuring the distance the plug moved in the pinion with each increment of load. The

yield point was found to be at 40,000 pounds plug-pressure for normalized and 25,000 pounds for un-normalized pinions.

As a further evidence of having passed the yield point, the

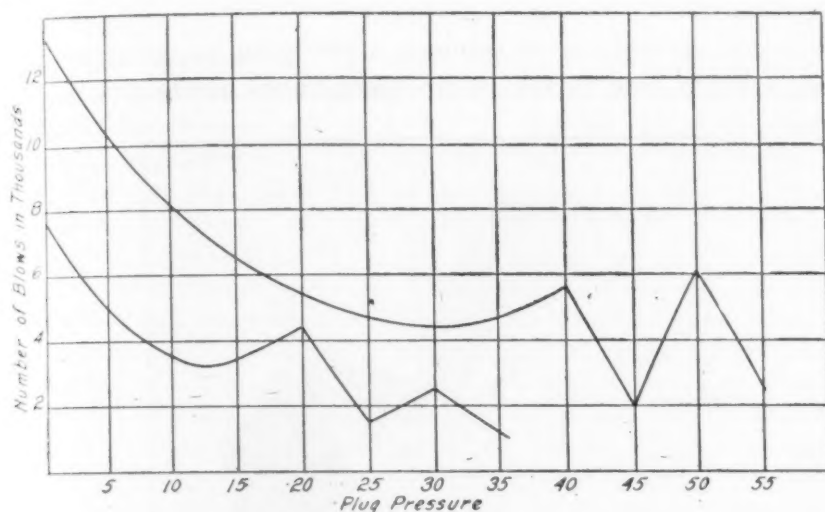


Fig. 11—Shows the Effect of the Mounting stress on Tooth-strength. The upper Curve represents a Pinion having been normalized at 900 degrees Cent. (1652 degrees Fahr.), and water-quenched at 760 degrees Cent. (1400 degrees Fahr.); the lower curve, that of a pinion hardened at 800 degrees Cent. (1472 degrees Fahr.).

force required to remove the tapered plug after each test was measured and recorded. The results of a single series follow:

Plug Load	Load Required to Remove Plug
5,000	4,900
15,000	14,900
22,500	17,500
25,000	4,370

The results of impact tests reported, are the average of single teeth broken from three pinions, each pinion having the same radial bore pressure.

Service fractures show all degrees of angularity, from the flat break of the pinions with low mounting stresses to the very sharp angle of highly stressed pinions. As an example, Fig. 12 shows the result of a mounting stress so high as to nearly burst the pinion and with light torque loads soon fatigued in operation.

When several teeth were broken from a single pinion, without removing the plug, each successive tooth was found to have a higher resistance. For instance, in one of the tests with a plug-pressure of 30,000 pounds, the first tooth required 1028 blows for fracture;

the second tooth 2658 blows, the third tooth 3633, and the fourth 4383 blows. This shows, as previously stated in this paper, that with the removal of each tooth, an equalization, or reduction of stress, occurs.

It seems, in conclusion, almost superfluous to call attention to the remarkable way in which the predictions made as a result of



Fig. 12—Shows an example of a service fracture resulting from very high radial stresses.

these stress analyses by the photoelastic method were verified by the mechanical tests. These studies show how good design and metallurgically sound material may be jeopardized by unintelligent or careless assembling which produces abnormal local stresses resulting in premature failures.

When the tooth fracture extends deeply into the pinion core, mounting stresses have probably been dangerously high. A little experience on the part of the operator in judging these fractures should enable him to render accurate reports on such failures.

STEEL UNDER THE OXYACETYLENE FLAME

BY A. S. KINSEY

Abstract

In the burning of the oxyacetylene flame, which produces a temperature of about 6300 degrees Fahr., a border combustion occurs which makes it possible to melt steel without oxidizing it. Also the fact that the rate of supply of carbon to the flame can be easily regulated by the flow of acetylene makes it possible to bring steel to its molten state without any loss of its chemical elements. Odd shapes and sizes of steel to be hardened, tempered or annealed may easily be heated with the oxyacetylene torch, which has the additional advantage of being adaptable to confined areas. Special jobs of carburizing can be done with the flame, the cement carbon being obtained from an excess of acetylene supplied to the torch. The economy and efficiency of the oxyacetylene flame is largely attributable to the remarkable purity of the 99.5 per cent oxygen, now commercially available over the country.

THE oxyacetylene torch produces an unusually interesting flame for the heating and melting of metals, which is particularly true for steel. As the term implies, the combustible gas of the flame is acetylene, and in order to get the full benefit of the heat of its carbon it is burned in an atmosphere of oxygen. An efficient oxyacetylene flame requires that both of these gases should be of good quality. Much advancement has been made in this regard, and it is assumed that a few thoughts on this part of the subject will be of interest.

OXYGEN

A large proportion of the compressed oxygen sold in the United States is manufactured by the Claude liquid air process. This is accomplished by compressing ordinary air, after it has been relieved of its carbonic acid gas, to a pressure of nearly 500 pounds per square inch, after which the air is cooled to about 80 degrees Cent. below zero by air which has been previously chilled. The air is then expanded and liquified at a temperature of about 180 degrees Cent. below zero. Rectifying the liquid air causes the

A paper presented before the Spring Sectional Meeting, Moline, Ill., May 22 and 23, 1924. The author, A. S. Kinsey, is professor of shop practice, Stevens Institute of Technology, Hoboken, N. J.

nitrogen and oxygen to separate, due to the fact that liquid nitrogen becomes vapor at 196 degrees Cent. and liquid oxygen at 183 degrees Cent. The pure oxygen is compressed into specially manufactured steel cylinders, which usually hold 220 cubic feet at a pressure of 2,000 pounds per square inch. Much study has been given to the purity of oxygen, and undoubtedly it will be of interest to state that it is now possible to supply the trade with compressed oxygen at a purity of 99.5 per cent, with a tolerance of one-tenth of one per cent either way.

ACETYLENE

The fact that acetylene has proved to be such an exceptionally useful and efficient gas in the manufacture and repair of metals and in other applications to engineering shop practice may justify some remarks about this unusual gas.

Acetylene is made from calcium carbide and water. Calcium carbide is manufactured by the chemical combination of calcium and carbon, the calcium being obtained from lime and the carbon from coke. These two raw materials are crushed, thoroughly mixed and then fed around the electrodes of an electric furnace, which melts and fuses the whole mixture. This molten carbide is solidified in a big mold, and when cold is crushed and reduced to the small sizes required by the market.

When calcium carbide is dropped into water the result of the chemical reaction is the formation of acetylene gas and slaked lime. One pound of carbide will produce about 5 cubic feet of acetylene.

There is no other gas in common use containing as high a percentage of carbon as acetylene, nor is there any supply of gaseous carbon equal to that found in acetylene. And, with the exception of the electric furnace, there is no other heat so intense, so concentrated and so convenient of manipulation as acetylene burned in an atmosphere of oxygen as, for example, through an oxyacetylene welding torch.

Acetylene has a peculiar property which greatly enhances its value as a combustible gas. Gases generally are divided into two classes, one having the characteristic of generating heat during the chemical reaction of its formation and called *exothermic*, and the other absorbing heat during its formation and known as being *endothermic*.

There are only a few endothermic gases, one of which is acetylene. Its property for absorbing heat when its elements are combined is higher than any other gas except one, being equal to 227 B. t. u. per cubic foot of gas. The source of this heat in acetylene may be explained by the fact that when calcium carbide is dropped into water it slakes, that is, chemical reaction occurs between the lime in the carbide and the water, and this reaction develops heat which is stored in the molecules of acetylene gas. When acetylene starts to burn, as in the oxyacetylene welding torch, its first temperature of combustion is about 4,000 degrees Fahr., the stored up heat of the gas is then released, which causes the temperature to rise to about 6,300 degrees Fahr. This is due to the endothermic property of the gas, which is probably its chief asset, and has had much to do with making it the most efficient of all gases for the welding and cutting of metals. It not only contains an unusually large amount of heat, to the extent of 1685 B. t. u. per cubic foot, but also has the characteristic of releasing these heat units at so rapid a rate that the highest temperature of the flame is supplied instantaneously. In the early history of the use of acetylene it was the practice to distribute it as a free gas in tanks which were otherwise empty, but it is now sold entirely in the *dissolved* form. That is, the gas is compressed into specially prepared acetylene cylinders, which are manufactured of the best steel and in accordance with the regulations of the Interstate Commerce Commission. These cylinders are packed with a porous earthy material, like infusorial earth. Acetone is poured into the filler, and when acetylene gas is charged into the cylinder the acetone absorbs and dissolves it. This increases the volume and pressure of the acetone, but when its pressure is reduced, as in the opening of an acetylene cylinder, the gaseous acetylene is released by the acetone and passing through a pipe or hose to a welding or cutting torch it may be used without risk of explosion.

THE OXYACETYLENE FLAME

The high percentage of carbon in acetylene requires a special provision for its combustion, as is shown by the chemical formula for its reaction:



indicating that the combustion of acetylene and oxygen produce

carbon dioxide and water vapor. From this it may be seen that it requires 2.5 volumes of oxygen for the complete combustion of acetylene. A large proportion of this oxygen is obtained by the flame directly from the air, but the remainder must be supplied from another source, which is the steel cylinders of compressed oxygen. This combustion of pure oxygen and rich carbonaceous acetylene has produced the most remarkable flame ever supplied for certain applications of heat to metals. For example, before the advent of the oxyacetylene torch practically all welding was accomplished by the old forge practice of heating the metal to the soft plastic condition and hammering the two ends together, and as the success of this weld depended on the metal being brought to the plastic state, only metals having such a plastic state could be welded. This limited welding to wrought iron and low carbon steel. When the oxyacetylene flame became available a new way to make welds was discovered, which depended on the principle of *fusion* rather than that of *plasticity*. With the oxyacetylene flame a weld can be made by melting the ends of the two pieces of metal and running the mass together so that when it cools the joint becomes one having a strength practically equal to the unbroken bar. In substituting the principle of fusion for plasticity the limits of welding were therefore extended from wrought iron and steel to all the other metals of the ferrous group, and to those of the non-ferrous group like the coppers, brasses, bronzes, aluminum, nickel, etc., but undoubtedly the metal which has benefited most from the use of the oxyacetylene flame has been steel.

HEATING STEEL

The application of heat to steel is always an interesting study, and especially is this true when the heat is from a flame of a temperature of about 6,300 degrees Fahr. When it is required to raise the temperature of an important piece of steel to a red hot or molten condition two things must be considered: (1) the effect on the chemical nature of the metal, and (2) the change in its physical properties.

CHEMICAL CHANGES

In addition to the iron in the metal, the chemical elements

of ordinary low carbon steel are carbon, manganese, silicon, phosphorus and sulphur. Each of these has its peculiar effect on steel, especially the carbon, manganese and phosphorus. In the making of steel the proportions of the chemical elements are carefully considered, and any later heating of the metal should not be done at the expense of a change in these proportions. This, however, has always been considered practically impossible. The carbon in steel seriously affects its strength. If the pure metal or ferrite has no carbon or any of the other common chemical elements in it, its tensile strength would not be more than about 5,500 pounds per square inch. To add, say 0.15 per cent of carbon, as would be found in low carbon steel, would increase the tensile strength about ten times to 55,000 pounds per square inch. Add more carbon, say to 1.00 per cent, and the tensile strength may be raised to 100,000 pounds per square inch. Therefore, to change the carbon in steel directly affects its tensile strength. Manganese in low carbon steel gives the metal toughness, durability and good bending qualities. Manganese is very sensitive to the oxygen of the air, and when steel is red hot or molten its manganese is liable to be oxidized, which would leave the metal brittle and cold-short. Therefore, considering only these two chemical elements and their influence on steel, it will be seen that the ideal to be sought is to be able to heat the metal without the loss of its desirable chemical nature, and in this regard the oxyacetylene flame has proved of high value. Its chemistry is peculiarly interesting. Take, for example, the melting of steel for a fusion weld. When the oxyacetylene flame is pressed down upon the metal the outer part of the flame, or *envelope*, covers the molten metal and thereby insulates it from the air, and, because of the character of the flame, a neutral atmosphere is created which prevents the removal of the chemical elements of the steel. This is due not alone to the complete combustion within the envelope of the flame produced by a sufficient supply of pure oxygen, but chiefly to the principle of the *border combustion* of the flame. That is, as the carbon from the acetylene is sent into combustion by the extra supply of pure oxygen through the torch, the products of combustion thrown off at the point of the inner flame cone consist of hydrogen and carbon monoxide. These gases cannot burn inside of the flame because of the high temperature at the cone. They, therefore, move outward to the border

of the flame where they reach the atmosphere and are cooled. Then they combine with the oxygen of the air and burn, the hydrogen forming water vapor and the carbon monoxide changing to carbon dioxide. The carbon monoxide has a strong affinity for oxygen, and it, therefore, combines with the oxygen of the air on the edge of the flame envelope. It might otherwise pass through it, and change the composition of the metal. It will be of interest to add that when the first combustion of the oxygen and acetylene occurs, yielding hydrogen and carbon monoxide at the tip of the cone, a temperature of about 6,300 degrees Fahr. is produced. Then when the hydrogen burns and forms water vapor the temperature is about 3,800 degrees Fahr., and when the carbon monoxide changes to carbon dioxide the temperature is further reduced to about 2,300 degrees Fahr. In this remarkable flame, therefore, may be found a range of temperatures from 6,300 degrees Fahr. at the cone tip, to 2,300 degrees Fahr. at the end of the envelope.

PHYSICAL CHANGES

When a piece of steel is made red hot, or brought to the molten state, important changes occur in its granular structure, and in the absence of the microscope one may visualize the marvelous movements of the crystals and grains. Steel is composed of grains having from four to eight flat sides. Each grain is formed of a group of crystals which look somewhat like ferns, and which arrange themselves so that their projecting parts interlock and fit together. The space between the crystals is so slight that it can be seen only with a powerful microscope, while the space between the grains is greater and more easily discerned, sometimes even with the naked eye if the metal is unduly strained. The wonderful part of the grain structure of steel is the natural law which holds the crystals and grains together, and which is generally believed to be the law of cohesion or attraction of one particle for another, varying in force according to the nature of the material. A newer theory, however, is that a metallic cement supplied by nature holds the crystals together. Be this as it may, a piece of cold steel composed of the wonderfully formed minute crystals makes a mass so strong that it will require a pulling force, or tension, of many thousands of pounds per square inch to separate them. This is steel

in its natural refined condition as it is found at atmospheric temperature. But when heat is applied to it the metal is changed from its natural state to one which requires special consideration of the physical law governing its crystallization and strength when hot. For what it required, say 50,000 pounds per square inch to accomplish with the metal in the cold condition, may easily be brought about with heat, without strain, so far as the force of granular attraction is concerned. In fact any source of high temperature will melt steel, but it may be accomplished at the expense of the refined condition of the grains, and the possibility of restoring the heated metal to its original solid granular structure and strength. The ideal flame for the heating of steel is that which will create about the hot metal such an atmosphere that the re-assembling of the grains may be accomplished without interference from oxides or changes in the chemical elements. But by the very nature of things this has not been very easy of accomplishment, and a brief consideration of the effect on the grains of applying heat to steel may be of interest at this point. When heat is applied to a piece of steel the grains and crystals at once begin to move, due undoubtedly to the reduction of the force of cohesion by the heat. The crystals unlock and separate, the grains slide on their flat surfaces as the expansion from the unlocking crystals takes place, and the whole mass slowly disintegrates in an orderly manner according to the law of expansion from the reduction of cohesion as the tension lowers. Less and less this cohesion becomes until the tensile strength has dropped from say 55,000 pounds per square inch when the metal is cold, to about 40,000 pounds per square inch, at 1,000 degrees Fahr., and when the metal has become liquid the cohesion is nearly gone and the tensility is almost nil. It is also in its weakest condition, chemically speaking, for the oxygen of the air will try to combine with it, which would result in the formation of oxides, and the chemical elements of the metal will try to change their positions and characteristics. Then when the metal is allowed to cool, the law of cohesion operates again, the crystals readjust themselves to their old positions, as the metal is restored to its former condition. That is, that is what should occur, but it cannot be successfully accomplished unless the atmosphere surrounding the hot steel has been of a nature to prevent oxidation, for when oxygen attacks steel in the molten condition the pure iron,

or ferrite crystals, burn on their surfaces and the resulting ash, or oxides get between the crystals and interfere with their sliding action so that they cannot get closely together again.

There is also another thought which should enter here regarding the rapid heating of steel. The crystals must have time to unlock or their shapes will be deformed, and finally when the metal cools and the crystals reassemble they will not go together properly, and the piece of metal will be coarse-grained and weak. That a piece of steel may be heated too quickly is well known, and the fact that while the oxyacetylene flame will heat the metal as fast as may be necessary by the simple change of torch tips, its natural rate of penetration is one of its chief assets.

Therefore, considering the two principal risks to the physical structure when heating steel, i. e., the interference of granular movement by oxidation and the deformation of the crystals, the oxyacetylene flame is peculiarly applicable to such work. Its neutral atmosphere and its disposal of the products of combustion, make the prevention of oxides practicable in ordinary shop conditions, and at the same time the shape and character of the flame make it possible to supply heat to a piece of steel enough faster than the rate of conduction to promptly bring the metal to the molten condition, as in the case of a fusion weld, and still not have the rate of heat supply so fast that the crystals are deformed.

HEAT TREATMENT OF STEEL

The principle involved in what has been said regarding the merits of the oxyacetylene flame for melting low carbon steel may also apply to the heating of high carbon steel for special heat treatment, but of course it is hardly to be expected that the oxyacetylene torch will be applicable to the heat treatment of high carbon steel parts on a production basis. There are times, however, when hardening is desired on special parts of a job, particularly down in a cavity, or over some confined area not easily reached by an ordinary source of heat, and under these conditions the oxyacetylene flame, as found for instance in a welding torch, provides a practical available means of heating the metal. The torch also has the advantage of making it possible to introduce an excess of acetylene in the flame, which makes it of a carburizing nature, and thus

prevents the loss of carbon from the steel when it is being heated. This insures that the final carbon content of the metal is the same as before heat treatment. The oxyacetylene flame is also a con-

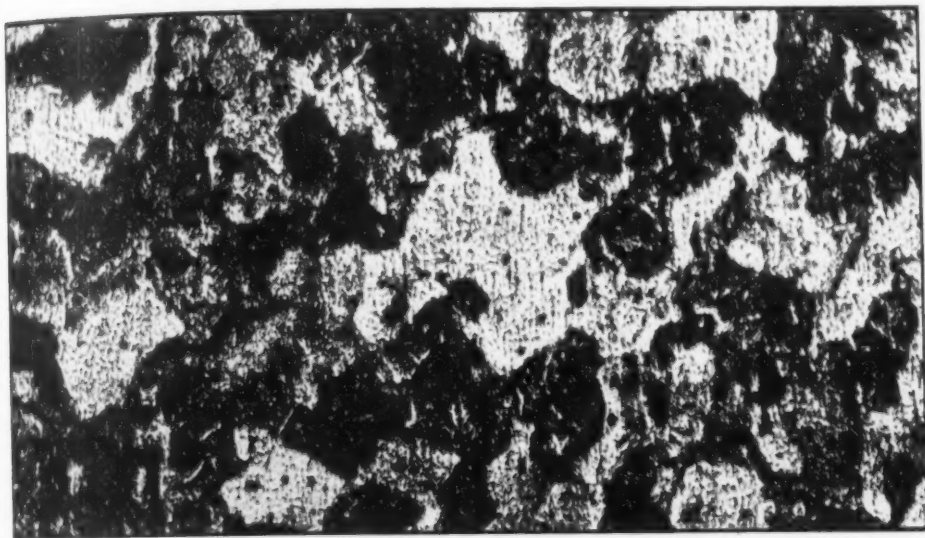


Fig. 1—Low Carbon Steel Before Welding. Magnified 175x.



Fig. 2—Low Carbon Steel After Welding. Magnified 175x.

venient source of heat for the annealing of high carbon tool steel, and especially is this true when such annealing is required within confined limits. Again it is practicable to use the oxyacetylene flame for special cases of temper drawing. A piece of steel

tempered to a straw, for example, might easily be heated and re-tempered to a brown or blue with the oxyacetylene torch, and here again the non-oxidizing nature of the flame would be of value in preventing interference with the temper colors of the high carbon steel.

Low carbon steel heated to the usual carburizing temperature of, say, 1830 degrees Fahr., may be made to absorb a small amount of carbon from an oxyacetylene flame operated with an excess of acetylene, and a modified degree of case hardening or carburizing may be conveniently obtained in this manner. The carbon monoxide produced by the burning of the carbon in the acetylene will serve as a carrier of minute particles of unburnt carbon into the grains of the steel and thereby increase the carbon content of the metal sufficiently for it to take a hardening effect by simple quenching in cold water. The rate of penetration of the carbon from this source is almost as rapid as when ground-bone is used. The portability of the torch, and its ready supply of free carbon in the gaseous form, frequently prove a convenience in the carburizing of special small jobs or at certain places on bigger work.

Comment and Discussion

Papers and Articles Presented Before the Society and Published in Transactions Are Open to Comment and Criticism in This Column—Members Submitting Discussions Are Requested to give Their Names and Addresses

DISCUSSION OF P. E. MCKINNEY'S PAPER ON "PROBLEMS OF THE HEAT TREATER AS INFLUENCED BY THE PRE-NATAL HISTORY OF THE MATERIAL."*

By G. F. COMSTOCK

WHILE the writer is in entire agreement with the author on the main points brought out in this paper, and with the conclusions, there are a few details connected with the interpretation of the photomicrographs which, in the writer's opinion, give a misleading impression. One point of this kind is the title of Fig. 1, and the description of Figs. 1 and 2 on Page 60, where it is strongly implied that the inclusions shown are oxides. While, of course, the identification of these particular inclusions cannot be questioned from a simple inspection of the photomicrographs, the writer would like to emphasize the fact that in his experience with a large number of specimens of cast steel showing this same type of fine inclusions arranged in irregularly curved streaks, they have always been found to be sulphides, and not oxides. A simple method for distinguishing between these two kinds of inclusions has been published in the *Transactions* of the American Institute of Mining and Metallurgical Engineers (Vol. 56, 1916, P. 553). Inclusions of the same color are shown in the author's Figs. 5, 7 and even 3, and these are probably all sulphides. The difference between specimens like Figs. 1 and 5, for instance, is generally not in the kind of inclusions present, but in their form and arrangement. It seems too bad that the reader of this paper should get such a strong impression that inclusions similar to those shown in Figs. 1 and 2 are oxides when, as a matter of fact, they are sulphides in at least the vast majority of cases, if not always, and even here no good evidence is offered to show that they are not sulphides in this case also.

The cause of the arrangement illustrated by Figs. 1 and 2 cannot be connected with "expulsion of oxide" because this arrangement is nearly always found in cast steel that has been treated with aluminum, one of the strongest deoxidizers known. The connection between the use of aluminum and this inferior arrangement of the sulphides is not yet clear to the writer, but experience has shown that few steels treated with aluminum do not show at

*A discussion of P. E. McKinney's paper which appeared in the July 1924, issue of *TRANSACTIONS*, page 51, by George F. Comstock, physical testing laboratory, Titanium Alloy Mfg. Co., Niagara Falls, N. Y.

least some traces of this arrangement, while, when aluminum is not used, the sulphides are generally globular and scattered. It is probable that the teeming temperature has an important effect on the arrangement of the sulphides, but we have not yet been able to work out the exact relation.

The description of Fig. 13 is another point which is decidedly open to criticism. This photomicrograph is a good illustration of a ghost line with *sulphide* inclusions. It is pretty generally accepted that ghost lines are a manifestation of segregation, intensified by the evolution of gas during solidification of the steel. The gas is the product of a reaction between iron oxide, coming out of solution in the steel, and the carbon in the steel. Deoxidizers prevent this reaction by combining with the oxygen so that it is not available to form carbon monoxide. Thus deoxidizers reduce segregation by allowing the steel to freeze quietly, without having the impure, last-freezing portions collected into channels and pockets by rising gases.

The trouble in the case of Fig. 13, therefore, was that the deoxidation was not efficient, and gas was allowed to form. The metal surrounding the inclusions was not affected by any violent reaction with a deoxidizer, but was simply high in phosphorous as well as sulphur, on account of segregation. As has been shown by Stead, ('Iron, Carbon, and Phosphorus', *Journal of Iron and Steel Institute*, 1915, No. 1 and 1918 No. 1) it is the high phosphorus in ghost lines which drives out the carbon and makes their structures appear so different from the surrounding structures.

Slag inclusions such as are illustrated by Fig. 12 are not due to segregation, but are actually oxidized products resulting from the chemical reactions between iron oxide and the deoxidizers, or sometimes from the erosion of refractories. It is incorrect to differentiate between the inclusions shown in Figs. 12 and 13 by stating that the latter are "slag resulting from chemical reaction". That is what the inclusion in Fig. 12 probably is, while Fig. 13 illustrates merely sulphides, which are always found in all steel, but are here collected together by segregation.

In spite of the errors which are believed to have occurred in the interpretation of some of these photomicrographs, it is refreshing to note the clearness with which the various inclusions are shown, without the excessive pitting that disfigures so many published photomicrographs that are intended to illustrate inclusions in steel. Mr. McKinney is to be congratulated on the skill of the metallographist who prepared these specimens.

The Question Box

A Column Devoted to the Asking, Answering and Discussing
of Practical Questions in Heat Treatment — Members
Submitting Answers and Discussions Are Requested
To Refer to Serial Numbers of Questions

NEW QUESTIONS

QUESTION NO. 136. Which is the best pot for sheet galvanizing, one built up from heavy boiler plate, or a cast pot? If a cast pot, about what analysis?

QUESTION NO. 137. What is the mechanism of the iodine etch for the deep etching of steel?

ANSWERS TO OLD QUESTIONS

QUESTION NO. 98. What heat treatment will give a pure martensite structure throughout the hardened area of a piece of steel 6 x 2 x 3½ inches?

ANSWER. By James Sorenson, Metallurgical Engineer, Four Wheel Drive Auto Co., Clintonville, Wisconsin.

As the chemical analysis of the piece of steel in question is not given it is rather difficult to prescribe a suitable heat treatment which would produce a uniform martensitic structure throughout.

A high carbon chrome steel of the following composition, if given careful attention during the heat treatment, will produce an almost 100 per cent martensitic structure in the size specimen mentioned.

Chemical analysis:

	Per Cent
Carbon	1.2
Chromium	1.75
Manganese	0.60
Sulphur	0.04 or less
Phosphorus	0.035 or less

Heat Treatment: Heat to 1475 degrees Fahr. and quench in water at 80 degrees Fahr.

Due care should be given to the temperature of the quenching bath, also to the rate of heating.

QUESTION NO. 120. How does the carbon content affect the secondary hardness of high speed steels?

QUESTION NO. 129. *Does full annealing chromium and tungsten magnet steel, before hardening, affect the magnetic properties? If so, what is the cause?*

DISCUSSION. By D. K. Bullens, president, D. K. Bullens Co., Pottstown, Pa.

Referring to the answer of this question, as published in the August TRANSACTIONS, it is noted that Clinton Armstrong states as follows:

"The fact remains that full annealing of any piece of steel prior to hardening and magnetizing improves the quality of the magnet to a very marked extent and gives results which are approximately uniform."

It is noted that he states that his conclusions are "a fact." He, therefore, undoubtedly can supply the evidence which would make this a fact, and the writer would appreciate receiving the experimental work which leads to the conclusion which he has drawn. On the other hand, his statement is so far from coinciding with metallurgists of the most prominent steel companies and from our own experience and investigation as one of the largest manufacturers of permanent magnets in this country, that the evidence above requested would be of immense value to the trade in general, inasmuch as it would tend to entirely change the whole theory and manufacture of permanent magnets as it now exists both in this country and abroad.

DISCUSSION. By M. A. Grossmann, Dunkirk, N. Y.

It is unfortunately necessary to call attention to an incorrect answer given to this question in the August issue of the TRANSACTIONS.

Annealing, far from improving the quality of chrome and tungsten magnet steels, actually impairs the coercive force so seriously as to render the steels quite unfit for their original intended purposes. Further, they cannot by any heat treatment be made as good as unannealed steel. The steel is in its best condition for hardening and magnetizing when it is "as rolled." This is the term applied to the condition in which it leaves the rolls in the hot-rolling operation at the mill, being merely cooled in air, without any annealing.

Those are the facts. The theory involved is most probably as follows. Although magnetism is presumably a function of the electrons, it is apparently promoted by regularity and uniformity in arrangement of the atoms. This is quite to be expected, as there must be some optimum condition of the steel for magnetizability, and it would be desirable to have this condition throughout the mass of the metal. Now since carbon is essential to such magnet steel, and since the carbon plays such an all-important role in the hardening, it is probably desirable that the carbon be distributed as evenly as possible. Even distribution postulates fineness of division of the carbide particles—otherwise there would be likelihood of concentration gradients around the carbide regions after hardening, caused by incomplete diffusion. It is most probably here that the annealing has its injurious effect. When the steel has just been rolled, it is in its best condition as regards uniformity—the carbides are fine and the grains are small. When a steel in this con-

dition is hardened, it exhibits the best magnetic properties. But if the steel is annealed before hardening, the carbide particles have an opportunity to grow to considerable size, or new and larger ones are formed. In the subsequent hardening operation the diffusion of the carbide is then not sufficiently rapid to give complete uniformity.

Sometimes the steel as rolled is not soft enough to permit cold-shearing in subsequent manufacturing operations. It is then occasionally necessary to resort to a semi-anneal, corresponding to a low-temperature draw. But this must be done with great care, and even so will always reduce the coercive force somewhat. When machining or blanking operations must be carried out on the steel, it is necessary to compromise between the desirable machining qualities, which call for annealing, and the desirable magnetic qualities, which prohibit it.

QUESTION NO. 130. *Is there any advantage in using notched-bar impact tests in the inspection of annealed tool steel bar stock? What does such a test show?*

QUESTION NO. 131. *Given an alloy of the brass or bronze type, in which there are no critical transformation points, suppose that through carelessness the metal has been overheated, producing an undesirably coarse crystalline structure, is it possible to refine the grain without remelting or mechanical work?*

QUESTION NO. 133. *In annealing a carbon tool steel of 1.30 to 1.40 per cent carbon, are there any ill effects to the steel in allowing it to soak for an hour or more at 30 to 40 degrees Fahr. above the critical point?*

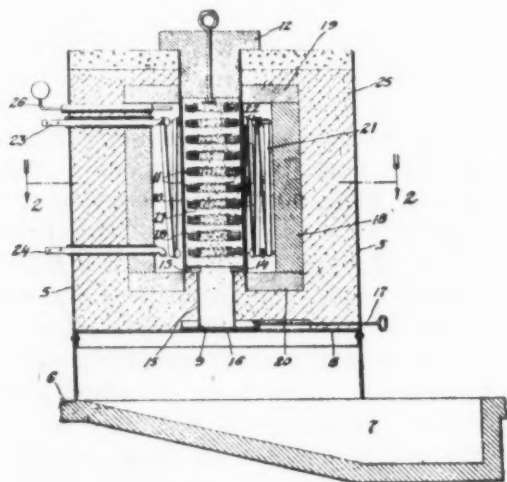
QUESTION NO. 134. *What are the usual feeds and speeds used in machining both carbon and alloy automotive steels, when using high speed steel cutting tools?*

QUESTION NO. 135. *From what material should the gears and pinions be made to be used in a galvanizing bath, that is, operated under molten zinc?*

ate. It is claimed that with the new compound, the articles to be hardened may be safely packed in contact with each other, that the hardening can be completed in a shorter time than ordinarily, that the compound removes the major part or all of the sulphur present in the steel, and that the steel which has been case hardened in this composition may be polished without producing rough spots in the surface thereof.

1,498,519, *Heat Treatment of Metallic Articles*, Henry L. Barton, of Detroit, Mich., assignor to General Motors Corporation, of Detroit, Michigan, a corporation of Delaware.

This patent shows a method and apparatus for carburizing and heat treating ring gears or the like by utilizing a continuous electric furnace and carrying out both the carburizing and heat treating steps without removing the articles from the furnace. The furnace 5 is provided with an



opening 9 in the bottom thereof, closed by a sliding door 16. The central heating compartment 10 is surrounded by resistant elements 21 connected to the terminals 23 and 24. The articles to be treated are packed with the carburizing material in a destructible container, such as a paper bag, and are dropped into the chamber 10. The top of the furnace is closed by means of a block 12. During the carburizing operation the bag is destroyed and when the necessary time has elapsed for the proper depth of case to be imparted to the articles the door 16 is opened and the carburized material is permitted to flow out of the furnace into the pit 7. The heating of the articles with the carburizing material removed is then continued until the desired temperature is reached for quenching, whereupon they may be removed and quenched.

1,501,183, *Method of Making Chromium Steel and Chromium Iron*, Napoleon Petinot, of New York, N. Y.

The patent relates to the method of producing chromium iron and steel.

In the present practice of making chromium steels a bath of molten steel is first prepared and then adjusted by suitable treatment to the desired composition of iron, carbon, silicon, manganese, sulphur and phosphorus and then toward the end of the heat ferro-chromium is added, so as to produce the desired amount of chromium into the finished steel.

This practice often results in the loss of a large amount of chromium by oxidation when the ferro-chromium is added, which unnecessarily increases the expense of producing chromium alloy steels.

A high carbon content in the ferro-chromium alloy prevents the loss of chromium by oxidation to a certain extent, but this is sometimes objectionable because it also often adds a certain amount of carbon to the steel, thereby disturbing the carbon contents of the finished product. According to the patent these difficulties are avoided by adding a ferro-chromium silicon alloy containing from 2 to 10 per cent silicon to the bath. The silicon prevents the chromium from oxidizing and also increases the amount of silicon in the bath, when this is desired.

1,501,184, Process of Manufacturing Alloy Steels in Electric Furnaces, Napoleon Petinot, of New York, N. Y., assignor to United States Ferro-Alloy Corporation of New York, N. Y., a corporation of New York.

In the manufacture of alloy steels in electric furnaces it is the usual practice to first make a plain carbon steel with a low sulphur and phosphorus content, and then to add the desired ferro-alloy to bring the bath to the desired composition, and since the ferro alloy contains carbon, it is necessary to make allowance for the added carbon, and where a low carbon alloy steel is required it has been exceedingly difficult to produce a sufficiently low carbon content by this method.

The inventor proposes to produce an alloy steel by first preparing a bath with a low carbon content in the electric furnace, removing the first slag and adding the ore of the metal which it is desired to combine with the steel. For example, if chromium steel is desired, chromium ore in ground form is added to the bath, the current is then applied sufficiently to melt the ore and form a chromium slag. The slag is then carburized with coke dust, anthracite coal, or the like, which forms carbides of lime, aluminum, magnesium, etc., and reduces the oxides of chromium and iron to metallic forms when the chromium and iron may be absorbed by the bath of steel.

Tungsten alloy steel may be formed in the same manner by adding scheelite. In this way the alloy steel of very low carbon content can be produced.

1,501,202, Steel and Process for Producing Same. Archibald H. Coplan, of Ottawa, Ontario, Canada.

This patent also relates to the producing of alloy steel with a low carbon content.

A bath is prepared from steel scrap with a low carbon content, and substantially all the carbon is removed by the use of preferably hematite iron ore. A ferro-chromium alloy of relatively high carbon content is heated for about 24 hours with an equal proportion by weight of iron ore or oxidized steel turnings to a temperature of approximately 2500 degrees Fahr. The carbon content of the alloy is in this way reduced from about 7 to about 3 per cent. The low carbon ferro-chromium is then added with the steel in the furnace to secure a product containing a very low percentage of carbon, about 0.06 per cent. The steel may be deoxidized by the use of a suitable scavenger and may then be cast into ordinary sand molds to produce articles which will resist strain and prevent warping when exposed to heat and acids.

1,501,425, *Process of Coloring Iron and Steel Black*, Wilhelm Uten-dorfer, of Cologne, Germany.

This patent describes a method of coloring iron or steel black by treating the articles to be colored with a heated solution of sodium picrate, gallic acid and an excess of free caustic alkali. The solution reaches its full active force with only moderate heating, so that sensitive articles, such as watch springs, precision instruments, etc., may be colored without producing any detrimental effect.

1,501,906, *Nickel Alloy*, Noak Victor Hybinette, of New York, N. Y., assignor to National Trust Company Limited of Toronto, Canada.

Mr. Hybinette has discovered that the small amount of silicon 0.5 of 1 per cent, heretofore considered necessary in the making of carburized nickel alloys, is not only unnecessary, but is harmful to the carburized nickel for many purposes.

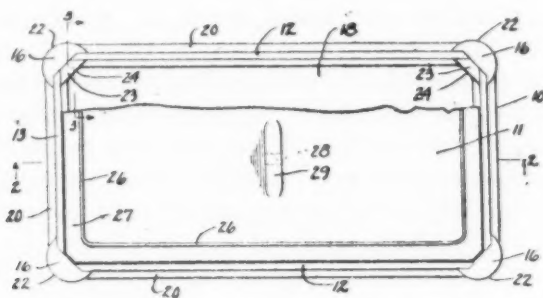
In the patent he describes a method of producing carburized nickel substantially free from silicon by melting electrolytic nickel and treating it with carbon which is free from silicon, carrying out the process in an apparatus having a lining which is free from silicon, as for example, a lining of magnesite.

Where the nickel contains silicon the silicon may be removed by subjecting it to a blowing action with air until the silicon is oxidized, and removing the silicon in the slag, then carbon is added to the desiliconized nickel until the desired amount of carbon has been absorbed. The carburized nickel, free from silicon, can be cast in metal molds without producing objectionable hardness and has several other advantages over carburized nickel which contains silicon.

1,502,973, *Carburizing Box and the Like and Process of Making Same*, Percy A. E. Armstrong of Loudonville, N. Y., assignor to Ludlum Steel Company, of Watervliet, N. Y., a corporation of New Jersey.

This patent describes a carburizing box, the walls of which are formed of separate cast or rolled sheets 12 and 13, which are placed in a mold

with the edges of the sheets 12 and 13 extending into the corners and bottom of the mold. The corner members 16 and the bottom member 18 are cast around the ends of the plates 12 and 13 to embed the ends and



secure the plates together. The material of the plates 12 and 13 and the cast corners and bottom is preferably the same, and the inventor recommends the use of "Silchrome" for this purpose.

The corners of the plates 12 and 13 may be keyed together by forming holes near the edges and permitting the cast metal 16 to flow into these holes to lock the corners and the ends together.

The inventor states that a box formed in this way is light in weight and can be used indefinitely for carburizing or other purposes where it is subjected to alternate heating and cooling without developing cracks or breaks.

1,502,425, Hardening Alloy for Bearing Metals and Process of Using Same, Robert Hughes Evans, of Detroit, Michigan.

This patent relates to a hardening alloy for babbitt bearing metal.

The inventor states that with the ordinary shop equipment it is often hard to add the high melting point hardening metals, particularly copper, to a bearing alloy, and he proposes to overcome this difficulty by preparing a hardening alloy at the factory containing the relative proportions of antimony, tin, copper, and bismuth necessary to produce the desired hardness and in such proportions that the melting point of the hardening alloy is considerably below the melting point of copper, so that in the preparation of a hardened bearing alloy the ordinary lead base alloy may be melted and the hardening alloy added in small pieces to the fuse lead bath to produce the desired degree of hardness in the bearings.

1,502,321, Bearing Metal Alloy, Karl Muller and Wilhelm Sander, of Essen, Germany.

This patent states that the addition of a small percentage of phosphorus, approximately 0.5 per cent, to the ordinary lead antimony bearing alloy will produce about 50 per cent increase in the Brinell hardness of the bearing and improve the physical properties, so that the tendency to scale or crumble and to abrasion in case the bearing runs hot, is greatly reduced.

Abstracts of Technical Articles

Brief Reviews of Publications of Interest to Metallurgists and Steel Treaters

THE DETERMINATION OF CARBON IN ALUMINUM. By R. J. Anderson and S. H. Brooks, metallurgists, in *Metal Industry*, August 1924, page 318.

A comparison made by the authors of various methods for estimating the carbon content of aluminum, shows that the best method entails the combustion of the metal with an oxidizing reagent.

DURALUMIN—ITS COMPOSITION AND TREATMENT. By S. H. Phillips, in *American Machinist*, September 4, 1924, page 371.

The author points out that extreme care must be taken in alloying duralumin; accurate temperature control is also important. The methods of working and machining are covered, as well as the physical properties of this metal. It is also pointed out that resistance to corrosion is governed by the heat-treatment.

GASES EVOLVED DURING CARBURIZATION. By V. E. Hillman, director of research, Crompton & Knowles Loom Works, Worcester, Mass., in *Iron Age*, September 11, 1924, page 611.

The author discusses the behavior of five solid commercial compounds. The theory of the process is also covered.

STRUCTURE OF TROOSTITE AND SORBITE. By O. V. Greene, metallurgist for the Philadelphia & Reading Railway Co., Reading, Pa., in *Iron Age*, September 11, 1924, page 615.

This article discusses a method of etching which develops the actual and complex constituents of carbon steels at high magnifications. Numerous photomicrographs are included showing the structure of these metals.

EFFECT OF CHANGES IN TOTAL CARBON AND IN THE CONDITION OF CARBIDES ON THE SPECIFIC RESISTANCE AND ON SOME MAGNETIC PROPERTIES OF STEEL. By E. D. Campbell and G. W. Whitney of Ann Arbor, Mich.

This paper was presented before the September meeting of the Iron and Steel Institute and discusses a method for preparing, on a laboratory scale, small steel bars differing only in carbon content. The results of measurements of specific resistance and some magnetic measurements on annealed and oil-hardened bars are given.

ON THE NATURE OF HIGH-SPEED STEEL. By M. A. Grossmann and Edgar C. Bain, Dunkirk, N. Y.

The above paper was presented before the September meeting of the Iron and Steel Institute, and gives a more or less complete account of the physical phenomena occurring in high-speed steel from the time of casting the homogeneous melt to the production of the hardened tools. The changes in the nature, amounts and distributions of the well-known constituents of this steel are covered.

RESISTANCE OF METALS TO REPEATED STATIC AND IMPACT STRESSES. By R. R. Moore, chief, physical testing branch, engineering division, U. S. Air Service, McCook Field, Dayton, Ohio.

This paper was presented at the June meeting of the American Society for Testing Materials at Atlantic City, and gives the results of tests made at McCook Field to determine limits of some ferrous and non-ferrous metals; the effect of a notch and of cold working on these endurance limits and the resistance of these metals to impact stresses. A comparison of endurance limits with other physical properties is also made.

AN ACCELERATED ELECTROLYTIC CORROSION TEST. By R. J. Anderson and G. M. Enos.

The above paper was presented at the June meeting of the American Society for Testing Materials at Atlantic City, and reports the results of experiments carried out in the development of an accelerated electrolytic test for corrosion.

CHARACTERISTICS OF MATERIAL FOR VALVES OPERATING AT HIGH TEMPERATURES. By J. B. Johnson and S. A. Christiansen.

This paper was presented at the June meeting of the American Society for Testing Materials at Atlantic City, and describes the results of laboratory tests and single-cylinder and multiple-cylinder engine tests of steels proposed for valve use.

STAINLESS STEELS, THEIR HEAT TREATMENT AND RESISTANCE TO SEA-WATER CORROSION. By Jerome Strauss and J. W. Talley, U. S. Naval Gun Factory, Washington, D. C.

The above paper was presented at the June meeting of the American Society for Testing Materials at Atlantic City. Tests for the determination of physical characteristics and an extensive study of their behavior when subjected to sea-water spray were made on almost thirty commercial corrosion-resistant steels in over twenty distinct compositions. Many observations concerning their behavior in tension, hardness, impact and salt-spray corrosion were made on samples subjected to a variety of heat treatments and are described in this article.

News of the Chapters

BUFFALO CHAPTER

At a recent meeting of the Buffalo chapter of the American Society for Steel Treating, the following members were elected for the ensuing year: chairman, M. A. Grossmann, 762 Central Ave., Dunkirk, N. Y.; and secretary-treasurer, J. L. Gibney, metallurgist with the W. P. Taylor Co., 575 Howard St., Buffalo, N. Y.

CINCINNATI CHAPTER

The Cincinnati chapter of the American Society for Steel Treating held their first regular monthly meeting on September 11th at 8:00 p. m. in the Ohio Mechanics Institute. W. R. Fleming, chief metallurgist with the Andrews Steel Co., was the speaker of the evening and chose for his subject, "The Manufacture of Basic Open Hearth Steel." A lively discussion followed this presentation.

HARTFORD CHAPTER

On Tuesday, September 9th, at 7:45 p. m., the Hartford chapter of the American Society for Steel Treating held a meeting in the Hartford Engineers' Club Rooms, 12 Haynes Street. C. H. Norton and H. W. Wagner, representatives of the Norton Company of Worcester, gave brief talks concerned with the grinding of metals, with particular reference to the effects of this operation on steel which had previously been heat treated. Having vast experience at their command they were able to demonstrate by actual tests and samples of ground work, the effects of proper and improper methods of grinding. Mr. Norton's talk was further illustrated by lantern slides. An interesting discussion ensued during these presentations.

LOS ANGELES CHAPTER

The Los Angeles chapter of the American Society for Steel Treating held a meeting on Wednesday, September 3rd, at 6:30 p. m., in the Los Angeles Creamery Cafeteria. Motion pictures on iron and steel were shown. The members were taken on an inspection tour through the Ford factory. This meeting was well attended.

PHILADELPHIA CHAPTER

The Philadelphia chapter of the American Society for Steel Treating held a meeting on September 12 at 8:00 p. m. in the Engineers' Club. "Observation" was the title of an interesting talk by Prof. C. O. Althouse, Central High School. A motion picture entitled, "Manufacture of Wire and Wire Rope," was shown through the courtesy of the John A. Roebling's Sons Co., Trenton, N. J. This film was explained by Dr. H. C. Boyton, metallurgist, and F. J. Maple. Dinner was served at 6:30 p. m. preceding the meeting.

Items of Interest

LARRY J. BARTON, consulting metallurgical engineer, located for some time at New Orleans, specializing on the electric furnace and its application to the foundry, has joined the Ohio Steel Foundry Company to have charge of research and metallurgical work at the Lima and Springfield plants of the company.

Francis B. Foley has resigned from the Bureau of Mines to take a position as metallurgist for the Lucey Manufacturing Corporation of Chattanooga, Tenn.

Two recent publications of the Tate-Jones & Co., Inc., of Pittsburgh, are Bulletin No. 175, which discusses Electric Heat Treating Furnaces, both of standard design and also gives illustrations of various furnaces built for special work; rotating hearth electric furnaces are also covered, including photographs of actual installations; also Bulletin No. 163-B, which covers Underfired Heat Treating Furnaces which can be utilized with either gas or oil.

It has been announced that arrangements have been made by which Automatic & Electric Furnaces, Ltd., and Electric Furnace Co., Ltd., London, will jointly design WILD-BARFIELD Internally-Heated electric furnaces, having an input greater than 25 K. W. It has also been arranged with the George J. Hagan Company of Pittsburgh, who have constructed a large number of electric resistance furnaces up to 350 K. W. capacity, for the use of their drawings and information, so that the best British and American practice will be incorporated in the designs.

The Electro-Metallurgical Co., 30 East Forty-second Street, New York, which has been manufacturing ferro-manganese in its electric furnaces in Norway, has recently become an active seller of this alloy in the United States. The alloy is made from imported ores and is offered in competition with the blast furnace product of the British and American producers.

A new development of automatic temperature control equipment employing the potentiometer method is announced by Wilson-Maeulen Co., Inc., 383 Concord Avenue, New York City. This equipment is designed for use on oil, gas, electric, or steam heated furnaces, and will operate

(Continued on Page 34 Advertising Section)

For

5 YEARS

in succession -- at Philadelphia -- Indianapolis -- Detroit -- Pittsburgh and at Boston

Q=ALLOYS

Have been the

LARGEST EXHIBITORS

Of Heat Resisting Alloys at the Exhibitions of
THE AMERICAN SOCIETY for STEEL TREATING.

Q=ALLOYS= {
DEPENDABILITY
UNIFORMITY
ECONOMY

Ask any one who visited the Boston Show.

We couldn't be so consistent in our advertising policy if we were not consistently successful with our manufacturing and sales policies. Business today is the best in our history.

GENERAL ALLOYS COMPANY
BOSTON, MASS.

When answering advertisements please mention "Transactions"

with standard power valves of motor driven, solenoid, or hydraulic type. The assembly consists of three standard interchangeable units. The power unit is a smooth running efficient $\frac{1}{4}$ H. P. Motor of commercial size and design, furnished for either A. C. or D. C. current. A strong, rugged reducing gear system, running in oil, transmits the power at proper speed to the control unit. The control unit employs the potentiometer method and is actuated by a thermocouple circuit using either base metal or Noble metal thermocouples. The galvanometer and all mechanical parts are standard and interchangeable. A temperature dial of 12" circumference provides a 12" temperature scale, making close and accurate temperature setting possible.

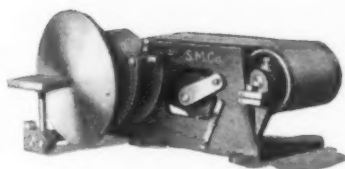
The unit feature of this equipment makes it convenient to build up multiple control capacity by adding additional control units to the same power unit, and control units may be added or removed without disturbing the balance of the equipment. All control units are provided with connections for additional units which may be added in multiple up to a total of six on the same power unit. The standard cycle of operation is ten seconds, but control units can be supplied for either five, ten, or twenty second cycles. The period of contact may be specified from one to seven seconds per cycle, to suit the requirements of various types of power valves. A wide variety of temperature ranges are furnished for many kinds of thermocouples. Efficiency, simplicity of design, and complete interchangeability of units and parts are the notable features of this control system. This equipment is now in production and complete descriptive literature is now being distributed by Wilson-Maeulen Company.

A new metallurgical microscope manufactured by Carl Zeiss of Jena, Germany, has just been placed on the market by George Scherr of New York City. This instrument, quite different from others, was designed to fill the demand for a metallurgical microscope rigid enough to be used directly in the shop or in the hardening room. It is not confined to the examination of small specimens cut off from the unfinished material, but it can be applied directly to the work itself during the entire process of manufacturing. In this manner, pieces of work which have developed defects in material, flaws, cracks, foreign matter imbedded, changes in structure due to strain, overheating or wrong thermal treatment are discovered before assembling or expenditure of useless additional labor. The time and money saving possibilities afforded by the use of this instrument will be readily appreciated. Microscopic examination of metal and alloys has assumed much importance in recent years, due to the fact that the structure of the metal, as exhibited by the microscope, is in direct relation to the qualities of the material. The new Carl Zeiss Microscope makes the experiences gained in this new science available to the superintendent and hardening expert. It brings the laboratory right into the shop. If interested, information will be sent upon request.

A satisfactory valve for an oxygen manifold, which must necessarily carry very high pressures, has always been a problem. The Oxweld Acetylene Company, however, after a study of several different designs, has developed a valve that meets every requirement. It has a swivel tip

To Prepare Metallographic Specimens

Metallographic Belt and Disc Grinder For Rough and Fine Grinding



3954

Rough grinding of metallographic specimens is done by successively grinding on three endless, interchangeable carborundum belts; coarse, medium and fine.

Each successive grinding is made at right angles to the previous one until the previous grinding lines are effaced and all lines become parallel. The fine grinding is then made with emery paper attached to the circular disk.

PRICE, complete with set of grinding belts -----\$60.00

Fisher Polishing Machine

By using the Fisher Polishing Machine and levigated alumina of the proper grade, the correct metallographic polish is obtained. The alumina is conveniently applied by means of a laboratory wash bottle.

PRICE, complete with 110 volt universal motor -----\$115.00



4570

Levigated Alumina for Metallographic Polishing

This is prepared by us by a special process developed in our own metallographic laboratory; it is free from rough particles and is much more satisfactory than rouge.

- 3957 Alumina, grade No. 1. For all hard metals. One ounce makes 50 ounces of correct polishing solution. Price, per ounce-----\$1.00
- 3957 Alumina, grade No. 2. For medium-hard metals. Especially suitable for cast-iron, bronze, brass and all nickel and copper alloys. One ounce makes 100 ounces of correct polishing solution.
Price, per ounce -----\$1.40
- 3957 Alumina, grade No. 3. For very soft metals and other metal specimens for investigation under highest possible magnifications. One ounce makes 167 ounces of correct polishing solution.
Price, per ounce -----\$1.80

SCIENTIFIC MATERIALS COMPANY
"Everything for the Laboratory"
PITTSBURGH, PA.

When answering advertisements please mention "Transactions"

on the stem. The body has a formed seat receiving the stem tip. This tip is attached to and carried by the stem by means of a swivel joint. Thus, the tip is enabled to seek its own natural seat in the body. The stem screw is in the inner end of the stuffing box, which is made gas tight into the body by means of the lead gasket. The stem itself is made gas tight by rubber packing, which is compressed between packing rings, by means of the hand wheel and nut.

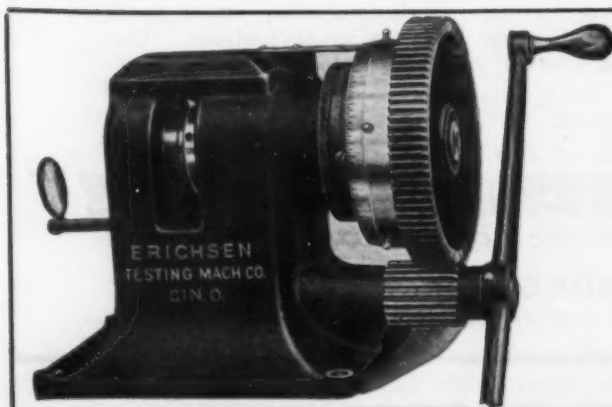
This new valve is absolutely fool-proof. If the operator should happen to unscrew the hand wheel all the way, there is no possibility of the internal parts being blown out by pressure, because the stem screws into the stuffing box. Even if he should unscrew both the stem and the hand wheel, the parts could not come out because the large end of the stem would lodge against the inner end of the stuffing box.

Tate-Jones & Co., Inc., Pittsburgh, recently received an order for twenty-four furnaces from the Bethlehem Steel Company for installation in the Sparrows Point, Md., plant. Twelve of these furnaces are Sheet Furnaces and twelve are Costello Patented Continuous Pair Furnaces. These furnaces will be stoker-fired and one stack will be used instead of separate stacks for the Sheet and Pair Furnaces.

At the present time one Sheet Furnace and one Costello Patented Continuous Pair furnace are being erected for the Weirton Steel Company, Weirton, W. Va. These furnaces are an addition to the sixteen furnaces installed last year by Tate-Jones Company and which are now in operation.

Eight Costello Patented Continuous Pair Furnaces at the Youngstown Sheet and Tube Company, Youngstown, Ohio, and three of these furnaces at the Thomas Sheet Steel Company, Niles, Ohio, are being erected at the present time.

At the annual autumn meeting of the Institute of Metals, held Sept. 8 to 11, the third autumn lecture was delivered by W. M. Corse of the National Research Council, Washington, who took as his subject "Recent Developments in Non-Ferrous Metallurgy in the United States With Special Reference to Nickel and Aluminum-Bronze." The lecture was illustrated by motion pictures.



Erichsen Testing Machines Standard the World Over

For the Determination of the Drawing, Stamping, Compressive and Folding Qualities (the "Workability") of Sheet Metals

Know your Metal.
Save time and save money.

The Bock Machine Company
3618 Colerain Ave. Cincinnati, O.

